

RESEARCH MEMORANDUM

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WITH TWO DIFFERENT SPINNERS AND AN NACA D-TYPE

COWL AT MACH NUMBERS UP TO 0.80

By George C. Kenyon and Robert M. Reynolds

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SUMMARY

An investigation has been made to determine the aerodynamic characteristics of a three-blade propeller designed to operate ahead of a D-type cowl. The propeller (designated NACA 3.638-(675)(057)-0572) in combination with two different spinner shapes and an NACA 1-62.8-070 D-type cowl was investigated at Mach numbers up to 0.80. The characteristics of the isolated propeller-spinner combination operating at positive thrust, negative thrust, and at near static conditions were also determined. Included are results of air-stream surveys of the local velocities in the plane of the propeller. All tests were made with the model at an angle of attack of 0° and at a Reynolds number of 1,000,000 per foot, based on free-stream conditions.

The efficiency of the propeller in the presence of the cowl was higher at all Mach numbers than that of the isolated propeller-spinner combination. At design cruise conditions (M=0.60, $\beta=53^{\circ}$), the efficiency of the propeller with the 1-series spinner and cowl was 80 percent, as compared with 72 percent for the isolated propeller-spinner combination. The onset of marked compressibility losses was delayed from a Mach number of 0.50 to a Mach number of 0.60 by the addition of the cowl.

The effects of inlet velocity ratio and spinner shape on the propeller characteristics were not large except at the higher Mach numbers (0.70 and 0.80).

INTRODUCTION

Considerable research has been conducted on propeller-spinner-cowling combinations suitable for use with large turbine engines (refs. 1 to 5). To augment this research, an investigation was conducted in the Ames



12-foot pressure wind tunnel to determine the characteristics of a three-blade propeller and a D-type cowl with both an NACA 1-series spinner and a more nearly conical spinner. The pressure-recovery characteristics of these propeller-spinner-cowling combinations have been reported in reference 6. Reference 7 has presented some preliminary results for the propeller with the cowl and spinners.

Presented herein are results of force tests, obtained concurrently with the data presented in reference 6, for the propeller operating in the presence of the cowl with the two different spinners. Also presented are force-test results for the isolated propeller-spinner combination operating at positive thrust, negative thrust, and at near static conditions. The velocity distributions in the plane of the propeller are included.

The tests were conducted for a range of blade angles from -20° to 63° and at Mach numbers up to 0.80. All tests were made with the model at an angle of attack of 0° and at a Reynolds number of 1,000,000 per foot, based on free-stream conditions.

NOTATION

blade width Ъ power coefficient, $\frac{P}{on^{S_{0}5}}$ thrust coefficient, $\frac{T}{on^2D^4}$ Ст blade-section design lift coefficient clq propeller diameter D HP horsepower maximum thickness of blade section h advance ratio, $\frac{V_0}{nn}$ J Mach number, $\frac{V}{8}$ M tip Mach number, $M\sqrt{1+\left(\frac{\pi}{J}\right)^2}$ Мt

speed of sound



- n propeller rotational speed
- P power
- R propeller-tip radius
- r blade-section radius
- S propeller disc area
- T thrust
- T_c thrust coefficient, $\frac{T}{\rho V^2 D^2}$
- U local velocity in the plane of the propeller
- V air-stream velocity
- Vo equivalent free-air velocity
- $\frac{V_1}{V}$ inlet velocity ratio
- β propeller blade angle at 0.75 R
- $\beta_{ ext{d}}$ design propeller-section blade angle
- η efficiency, $\frac{C_T}{C_P}$ J
- ρ air density

Subscripts

- 1 location of rake in cowl inlet
- a apparent (applied to propeller characteristics when operating ahead of the cowl)

MODEL AND APPARATUS

This investigation was conducted in the Ames 12-foot pressure wind tunnel with the model mounted on the 1000-horsepower dynamometer (described in ref. 8). A photograph of the model is presented in figure 1 and a sketch of the general model arrangement is given in figure 2. The propeller used was a three-blade type designed by Hamilton Standard Division and

Jan Service Services



it corresponded to the designation NACA 3.638-(675)(057)-0572. Blade-form curves for the propeller are shown in figure 3. Additional details of the model and its instrumentation as well as information on the full-scale design conditions can be found in reference 6.

Figure 4 is a photograph of the survey rake used to determine the velocity distribution in the plane of the propeller. The rake consisted of 24 static pressure tubes located at the radial stations listed in table I.

TESTS AND REDUCTION OF DATA

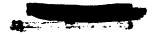
Thrust, torque, and rotational speed were measured (as described in refs. 2 and 8) for the propeller-spinner-cowl combinations and the isolated propeller-spinner combination (1-series spinner) for a range of blade angles from 33° to 63° at Mach numbers from 0.20 to 0.80. Data for the isolated propeller-spinner combination were obtained at negative thrust conditions at the same Mach numbers and blade angles and, in addition, data were obtained for this combination at a Mach number of 0.15 for blade angles from -20° to 25°. The characteristics of the isolated propeller-spinner combination were also measured at near static conditions for a blade-angle range from 10° to 25°.

Surveys of the air-stream velocity in the plane of the propeller were made at Mach numbers from 0.15 to 0.80. With the cowl installed, the effect of inlet velocity ratio on the local velocity in the propeller plane was also determined.

The Mach number used in this report was the average Mach number over the disc area as determined by velocity surveys reported in reference 8. For the tests made with the cowl installed, this Mach number (and the corresponding dynamic pressure) was corrected for blockage of the cowl by the method of reference 9. In no case did this correction exceed 1 percent.

The air-stream velocity (and, consequently, propeller advance ratio and efficiency) was corrected for the wind-tunnel-wall constraint on the propeller slipstream by the method of reference 10. Figure 5 presents a comparison of this correction with that determined experimentally by the method of reference 11 from measurements of wall pressures. The data included herein are for advance ratios at which the thrust-coefficient parameter $T_{\rm C}/(1-M^2)$ was greater than -0.5.

Analysis of the accuracy of the separate measurements of thrust, torque, and air-stream velocity, as in reference 8, indicates that errors in the propeller efficiencies reported herein are probably less than 2 percent.





RESULTS

The distribution of velocity across the propeller disc is listed in table I. These data are plotted in figure 6 for a few typical Mach numbers and inlet velocity ratios.

The characteristics of the propeller operating in the presence of the cowl are presented in figures 7 and 8 and the characteristics of the isolated propeller-spinner combination for conditions of positive thrust are presented in figure 9. The variation of maximum propeller efficiency with Mach number is summarized in figure 10 and the effect of inlet velocity ratio on the propeller characteristics is shown in figure 11.

The negative-thrust characteristics of the propeller-spinner combination are presented in figures 12 through 15 and the characteristics of the propeller-spinner combination at near static conditions are shown in figure 16 and are summarized in figure 17.

DISCUSSION

Propeller Characteristics at Positive Thrust

As in reference 2, the characteristics of the propeller operating in the presence of the cowl are presented as apparent values (figs. 7 and 8) since the determination of the propulsive thrust of the propeller was precluded by the fact that it was impractical, with the dynamometer arrangement used in the present investigation, to measure the increase in drag of the cowl and dynamometer parts within the influence of the propeller slipstream. The addition of the cowl behind the propeller resulted in reduced velocities throughout the propeller flow field, as evidenced by a comparison of figures 6(a) and 6(b) with figure 6(c). As a consequence of these reduced velocities (and in accord with the discussion of ref. 12), the thrust and power for the propeller operating ahead of the cowl were greater than that for the isolated propeller-spinner combination (at the same advance ratio), as can be seen from a comparison of figures 7 and 8 with figure 9.

Maximum efficiency.- As shown in figure 10, the efficiency of the propeller in the presence of the cowl was higher at all Mach numbers than that of the isolated propeller-spinner combination. At design cruise conditions (M = 0.60, β = 53°), the efficiency of the propeller with the 1-series spinner and cowl was 80 percent, as compared with 72 percent for the isolated propeller-spinner combination. It may be noted here that the higher efficiencies for the propeller with the cowl were due not only to interference effects but partly to the fact that, in the presence of



the cowl, the propeller was operating more nearly in the flow field for which it was designed.

The onset of marked compressibility losses was delayed (also as a consequence of the interference effects) from a Mach number of 0.50 to a Mach number of 0.60 by the addition of the cowl (fig. 10). The large losses in efficiency at Mach numbers from 0.60 to 0.80 were due not only to the effects of compressibility but also to the fact that at blade angles of 58.5° and 63° the inner portions of the blades were probably operating at negative thrust, since the local blade angles for this portion of the blade were greater than 90° (up to 98° for $\beta = 63^{\circ}$). Operation of the propeller at lower blade angles at these Mach numbers (requiring higher rotational speeds) might have resulted in higher efficiencies but was not permissible because of structural limitations of the model propeller.

Effect of inlet velocity ratio. Although the air-stream surveys (tables I(a) and I(b), and figs. 6(a) and 6(b)) show that decreasing inlet velocity ratio resulted in reduced local velocities at the propeller plane, the changes were small in comparison with the reduction in velocity occasioned by the addition of the cowl to the spinner (fig. 6(a) compared with fig. 6(c)). Consequently, as shown in figures 7, 8, and 11, the effect of inlet velocity ratio on the propeller characteristics was not large except at the higher Mach numbers (0.70 and 0.80), where small changes in local velocity resulted in relatively large changes in the propeller characteristics due to the effects of compressibility.

Effect of spinner shape. Although the data of figures 6(a) and 6(b) indicate only small differences in the local velocity distributions for the two spinners with the propeller removed, figure 11 shows that higher thrust and power coefficients were obtained with the propeller and modified conical spinner. However, as shown in figure 10, the differences in maximum efficiency were generally of the order of the stated accuracy of the results.

Propeller Characteristics at Negative Thrust

The data presented in figure 14(a) indicate that at any constant value of advance ratio, relatively constant negative-thrust coefficients were attained at blade angles from -5° to -20°. However, as shown in figure 15(a), the power coefficients corresponding to this range of blade angles increased rapidly, indicating that use of a more negative blade angle resulted in additional power absorption rather than an increase in negative thrust. For the range of blade angles and Mach numbers covered in the present investigation, there was practically no effect of compressibility on the negative-thrust and torque characteristics of the propeller at Mach numbers up to 0.60 (see figs. 14 and 15).



Propeller Characteristics at Near Static Conditions

The thrust and torque characteristics presented in figures 16(a) and 16(b) were obtained at near static conditions, as shown by the variation of velocity with nD in figure 16(c). The abrupt decrease in thrust coefficient and increase in power coefficient at values of nD below 60 are believed to be due to the effects of Reynolds number. At these low values of nD, the blade sections were operating at Reynolds numbers less than about 500,000.

The experimental data shown in figure 16 were used to compute the static thrust per horsepower and were then plotted as a function of power disc loading for constant values of nD. The envelope of these curves is presented in figure 17. The theoretical curve shown in figure 17 was computed by the method of reference 13. The variation of static thrust per horsepower with disc loading was adequately predicted by the theory, but the experimental values were only approximately 67 percent of the theoretical ideal values. However, the theory neglects rotational losses and blade drag which presumably accounts for the discrepancy between experiment and theory.

CONCLUDING REMARKS

The following remarks may be made regarding the results of the subject investigation.

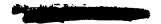
The efficiency of the propeller with the two different spinners and the cowl was higher at all Mach numbers than that of the isolated propeller-spinner combination. At design cruise conditions (M = 0.60, β = 53°), the efficiency of the propeller with the 1-series spinner and cowl was 80 percent, as compared with 72 percent for the isolated propeller-spinner combination.

The onset of marked compressibility losses was delayed from a Mach number of 0.50 to a Mach number of 0.60 by the addition of the cowl.

The effects of inlet velocity ratio and spinner shape on the propeller characteristics were not large except at the higher Mach numbers (0.70 and 0.80).

There was practically no effect of compressibility on the characteristics of the propeller-spinner combination operating at negative thrust at Mach numbers through 0.60.





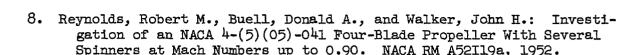
The propeller static thrust varied with power disc loading as predicted by actuator disc theory, but the experimental static thrust was only 67 percent of the theoretical ideal thrust.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Feb. 18, 1954

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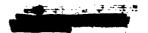


TABLE I.- LOCAL VELOCITY RATIO, U/V

(a) The 1-series spinner with cowl

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h, 04 .883 .993 .910 .911 .926 .931 .935 .874 .886 .895 .905 .914 .922 .877 .887 .886 .896 .90 .914 .926 .931 .935 .931 .882 .891 .893 .904 .913 .913 .913 .863 .878 .886 .893 .993 .995 .991 .995 .991 .997 .905 .906 .916 .924 .868 .889 .891 .897 .90 .906 .906 .906 .907 .908 .907 .914 .919 .873 .886 .891 .897 .90 .907 .914 .919 .873 .886 .891 .897 .90 .907 .914 .915 .907 .914 .915 .907 .915 .907 .915 .907 .915 .907 .915 .907 .915 .907 .915 .907 .915 .907 .915 .907 .915 .907 .915 .907 .915 .907 .90	920											-907													.947								- 1
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6.44 .905 .912 .921 .916 .929 .931 .938 .938 .912 .916 .907 .914 .919 .873 .886 .891 .897 .90 7.44 .926 .926 .926 .930 .938 .938 .938 .912 .916 .919 .922 .925 .930 .896 .906 .900 .891 .907 .91 8.44 .945 .947 .950 .947 .950 .928 .938 .938 .938 .938 .938 .938 .938 .93											.906		. [.891			.868		١.													5.04	ł
94، 1950. [202. [202. [202. [عطو. [مدو. [930. [930. [330. [عطو. [930. [عطو. [930. [طو. [940. [عدو. [طو. [-902																	-916	.921	.912	-905		. 1
8-W -947 -927 -920 -920 -922 -922 -922 -923 -923 -923 -923 -924 -924 -924 -924 -924 -924 -924 -924 -924 -924 -924 -924 -924 -924											-918	-907								.925			916		-938			-930		.926			· (
	937										944	.920 .940		939	.939		937			973	939		950		.964	-952 -964	950	.945	.950			9.44	.]
. به با		عيده.	ميره.	عبله.	صله.	مياه.	ميدو.	. 01			942		J.	.030			756		1:	.973	.974		010	.070	-90		060	.929			, yer		- 1
12.44 . 976 . 973 . 973 . 968 . 973 . 973 . 973 . 973 . 974 . 964 . 964 . 966 . 969 . 969 . 973 . 973 . 974 . 975	.95										977	.9 4 0	ş١	925	-923	١.	952	960	٠,	.962			.964	-964	-973		.973	.968	973				
96, 1890, 1890, 1990, 1990, 1990, 1990, 1990, 1990, 1990, 1990, 1990, 1990, 1990, 1990, 1990, 1990, 1990, 1990	967	967	967	967	967	967	967	.96	و. ا	۲)	-966	.968	٠)	.964	.967	1.	.965	973] .	.974			.976	976	.982	982	900	.960	985	.980		14.44	
970, 1971, 1979, 1979, 1979, 1979, 1979, 1979, 1979, 1979, 1989, 1989, 1979, 1989, 1989, 1989, 1989, 1984, 1	.972	-972	-972	-972	-972	-972	-972	-97	.9		-910		1	970		네 -	-970	976	t٠	.977	976	977	.978	-979	-979	981	.981	-979	96	981			i
797 777 6 377 979 978 979 978 979 978 979 978 989 889 8	978	978	.978	-976	.978	.978	.978	-97	۶. ا	11	.971	-977	:1	-976	-979	1	.978	272		.980				-984	985								:
	.986	904	.you	-yga(.ya	- year	- 904	-yo	٠,٧		.982 .985	903	H	.903			*201	綋	1 .	9556				.905	1.990	.990							j
98, 496, 396, 396, 996, 996, 996, 396, 396, 3	905	985	.905	.005	933	.900	097	- 00	í		.982	089						986	1:	.977					.000		-00°		977				1
96. اللهود ال196. 196. 196. 199	.986	.986	.986	.986	.986	.986	.986	.98	و. ا	u.J	.984	.981	iΙ	.987	967		.985			.990	.988				993		.99É		.998	.996			
96. [992. [992.] 992. [992. [992.] 449. [993. 499.] 499. [994. [994.] 499. [995.] 499. [995.] 499. [995.]	.989	.989	989	989	.989	989	.989	.98	9	9	.989	.991) [.990	-992	1	-991	992] -	.992	.994	-993	.99t	.994	.992	996	-996	994	-999	.998	994	26.44	}
99. (990، (990، (990، (990، (990، (990، (990، (990، (990، (990، (890، (890، (990، (990، (990، (44.)9											.990									992								-990	-997				į
99 999	.994	-994	.994	994	-994	-994	- 954	-99	و. ا	ᆀ	993	999	丠	995	·993	<u> </u>	-994	991	ئــــــــــــــــــــــــــــــــــــــ	993	.996	.994	-996	-995	.996	995	-999	-996	-999	-999	-999	32.44	

TABLE I.- LOCAL VELOCITY RATTO, $\text{U/V}\ \text{-}\ \text{Continued}$

(b) Modified conical spinner with cowl

Redial	N = 0.20								H =	0.40			L		M =	0.50		
station,		Inlet velocity ratio, V ₁ /V						Inlet	velocit	y ratio	, V ₁ /V			Inlet	veloci	ty rati	o, V ₁ /V	,
in.	0,48	0.55	0,65	0.84	1.02	1.36	0.43	0.53	0.63	98.0	0.96	1.35	0.42	0.53	0.63	0.83	1.04	1.3
3.34	0.881	0.897	0.912	0.927	0.937	0.954	0.871	0.900	0.905	0.920	0.928	0.945	0.866	0.897	0.903	0.920	0.926	0.93
3.59	.885	901	.911	.926	941	.956	870	.899	924	919	.929	, juli	.863	-896	904	917	-929	9.
3.84	.885	.901	.911	1.926	936	956	-870	.896	.922	917	926	940	.861	-898 -888	.900 .694	.915	925	.93
4.09	800	896	•906	.916	.931	.946	868	.894	899	-909	.919	.932	859	-888	.694	.907	•917) •9
4.34 4.84	.88	.900	-910	.915	.930	945	-875	.696	-904	.91 ¹	919	.932	.663	-890	.898	.911	915	9
4.84	884-	.895	•910	.915	.925	-940) . <u>877</u>	.893	-900	.908	.915	.925	.868	-866	.696	.907	.913	9.9
2-34	.898	-909	.919	.929	934	.939 .943	.890	.903	-905	.916	.920	,926	.869	-896	-902	.911	-917	.9
5.84	.908	-913	-923	-933	.938		905	.910	.912	.921	925	-933	.894	.907	923	.913	-983	و. ا و. ا
6.34	.518	.913	923	.933	.938 .917	-943	.908	.916	.918	.922	928	.936 .940	.898	909	913 986	.915	923	9.9
7.34	932	-937	.947 .956	.917 .956	961	.957 .961	.998 949	.930	930	935 956	931 921	.977	940	945	947	959	936	9.9
8.34 9.34	966	.952 .964	-971	.971	971	.976	.967	.962	962	.965	.964	.967	957	979	961	.959	961	9
10.34	975	975	.980	.900	.900	.985	.967	967	.967	.968	967	.961	963	.965	965	963	965	وّ: ا
12.34	984	994	989	989	989	.989	ادرو.	.079	973	.075	975	975	075	973	973	.982	.973	l já
14.34	987	982	987	.987	987	987	.987	973	984	973	.98	98	.975 .985	.985	.985	978	98	.9
16.34	.991	986	991	.991	991	.991	983	981	981	981	981	981	983	.983	963	985	-963	9.
18.34	.990	990	995	995	995	-990	.983	.983	983	983	966	983	.986	586	.966	986	986	۱.9
20.34	-995	995	1.000	995	995	1.000	998	.98e	992	989	-992	.990	.994	.990	.990	.986	-992	9.
22.34	.989	-969	.99k	.99k	.994	.994	994	.961	991	.988	991	.991	.989	.991	-991	-997	969	9.
24.34	.999	-999	1.004	1.004	1.004	1.004	.998	.990	-996	-996	993	•993	996	996	.996	998	99	9.
26.34	•993	988	-993	-993	.998	•998	-997	.969	995	997	995	-995	.996	-996	.996	.996	-99 ¹ +	-9
28.34	993	1.003	1.003	1.003	1.003	1.003	.996	988	994	994	994	.994	995	-995	995	-997	-995	1.9
30.34	.998	1.000	1.003	1.003	1.008	1.003	993	-993	-990	.990	993	•993	991	.991	-993	-991	.993	.9
32.34	-997	1.002	1.007	1.007	1.002	1.007	-997	.989	.994	.994	997	-997	-998	1.000	1.000	1.000	1.000	.9
Redial	и ≈ 0.60						N = 0.70						ļ <u>.</u>		И -	0,80		
station,	Inlet velocity ratio, V1/V						Inlat velocity ratio, V1/V						[Inlet	valoe1	ty rati	o, V ₁ /V	
in,	0.34	0.43	0.5	0.65	0.85	1.05	0.32	0.42	0.50	0,62	0.82	1.11	0.30	0.41	0.52	0.62	0.82	0.9
					0.912	0.917	0.856	0.860	0,883	0.894	0.907	0.916	0.838	0.865	0.874	0.884	0.894	0.9
3.34	0.867	0.885	0.893	0.898	U, 714	COST												
3.34 3.59	872	.888	.901	.902	.916	921	856	د88ء	885	.895	.907	-919	841	.867	.875	.884	,897	.9
3.3+ 3.59 3.84	.872 .867	.888 .683	.901 .898	.902 .898	916	921 917	856	.882 .877	.880	895 888	.901	.911	.837	.861	870	.880	.890	.9 9.
3.59 3.84 4.09	872 867 867	.888 .883	.901 .898 .886	.902 .898 .891	.906 .907	.921 -917 -910	856 853 847	.882 877 870	.880 .873	888 882	.901 .893	.911 .904	.837 .830	.861 .855	.870 .663	.880 872	.890 .682	.8
3.59 3.84 4.09 4.34	.867 .867 .867	.888 .883 .878 .879	.901 .898 .886	.902 .898 .891	.906 .907 .900	.921 .917 .910	856 853 847 851	.882 .877 .870 .873	.880 .873 .880	.886 .882	.901 .893 .896	.911 .904 .907	.837 .830 .836	.861 .855 .857	.870 .863 .865	.880 .872 .874	.890 .682 .883	8.
3.59 3.84 4.09 4.34 4.84	.872 .867 .867 .867	.888 .683 .878 .879	.901 .896 .886 .888	.902 .898 .891 .895 .893	.906 .907 .900 .902	.921 .917 .910 .912 .907	856 853 857 851 853	.882 .877 .870 .873	.880 .873 .880 .876	.888 .882 .885	.901 .893 .896 .890	.911 .904 .907	.837 .830 .836 .834	.861 .855 .857 .855	.870 .863 .865 .869	.880 .872 .874	.890 .682 .883	8. 8.
3.59 3.84 4.09 4.34 4.84	.872 .867 .867 .867 .868 .880	.888 .883 .878 .879 .879	.901, .898 .886 .888 .886	.902 .898 .891 .895 .895	906 907 900 902 900 908	.921 .917 .910 .912 .907	856 857 857 853 863	.882 .877 .870 .873 .810	.880 .873 .880 .876 .883	.888 .885 .883 .886	.901 .893 .896 .890	.911 .904 .907 .899	.837 .830 .836 .834 .814	861 855 857 855 862	.870 .863 .865 .869	.880 .872 .874 .872	.890 .682 .883 .883	.8
3.59 3.84 4.09 4.34 4.84 5.34 5.84	.867 .867 .867 .868 .880 .893	.888 .883 .878 .879 .879 .886	.901, .896 .886 .888 .886 .893	.902 .898 .891 .895 .893 .896 .905	906 900 900 900 900 900	.921 .917 .910 .912 .907 .909	856 853 847 851 853 863 863	.882 .877 .870 .873 .870 .880 .889	.880 .873 .880 .876 .883 .091	888 885 883 888 888	.901 .893 .896 .890 .896	.911 .904 .907 .899 .904	837 830 836 834 844 857	.861 .855 .857 .855 .862 .870	.870 .863 .865 .869 .867	.880 .872 .874 .872 .875 .883	.890 .682 .883 .883 .883	8.8
3.59 3.84 4.84 5.84 5.84	.857 .867 .867 .869 .880 .893	.888 .883 .878 .879 .879 .886	.901 .896 .886 .886 .893 .901	.902 .893 .891 .895 .896 .905	.906 .907 .900 .902 .900 .908 .910	921 917 919 919 907 907 907	853 853 853 853 858 858	.882 .877 .870 .873 .870 .880 .889	.880 .873 .880 .876 .883 .091	.888 .885 .883 .886 .895	.901 .893 .896 .896 .896 .904	.911 .904 .907 .899 .904 .910	.837 .830 .836 .834 .844 .857	.861 .855 .857 .855 .862 .870	.870 .863 .865 .869 .867 .875	.880 .872 .874 .872 .873 .883	.890 .682 .862 .863 .890 .890	888888
3.59 3.84 4.34 4.84 5.84 7.34	.872 .867 .867 .868 .880 .893 .898	.888 .878 .879 .879 .895 .895 .895	.901 .896 .886 .886 .893 .901 .903	.902 .893 .893 .893 .896 .905 .909	.90.6 .907 .900 .902 .900 .902 .910 .914	.921 .917 .910 .912 .907 .909 .917 .928	856 853 857 853 863 863 863 863 863	.882 .877 .870 .873 .870 .880 .889 .892	.880 .873 .880 .876 .883 .891 .894	.888 .885 .885 .886 .895 .897	.901 .893 .896 .896 .896 .904 .904	.911 .904 .907 .899 .904 .910	.837 .830 .836 .834 .844 .857 .868 .886	.861 .855 .857 .855 .862 .870 .874	.870 .863 .866 .867 .875 .879	.880 .874 .875 .883 .883 .884	.890 .652 .883 .863 .890 .890	888888
3.59 4.69 4.34 4.84 5.84 7.84 7.84	.872 .867 .867 .868 .880 .893 .898 .939	.888 .879 .879 .879 .886 .897 .936	.901 .896 .886 .886 .893 .901 .903	.902 .893 .891 .893 .896 .905 .909 .921	.906 .907 .900 .902 .900 .908 .914 .928 .943	917 910 912 907 907 907 907 917 928 943	853 857 853 863 863 863 863 863 863 863 863 863 86	.882 .877 .870 .873 .870 .880 .889 .992 .909	.880 .873 .880 .876 .883 .091 .991 .933	.888 .885 .883 .886 .895 .897 .913	.901 .896 .896 .896 .904 .904 .919	.911 .904 .907 .899 .904 .910 .910 .922	.837 .830 .836 .834 .844 .857 .869 .886	.861 .855 .857 .855 .862 .870 .874 .894	.870 .863 .866 .866 .867 .875 .875 .879 .996	.880 .874 .875 .883 .884 .900	.890 .662 .883 .862 .890 .991 .903	88.88 88.88 89.99
3.59 4.34 4.34 5.34 5.34 7.34 9.34	.872 .867 .867 .868 .880 .898 .898 .919 .939	888 8879 879 879 879 879 877 877 877 877	.901 .896 .886 .886 .893 .901 .903 .918 .921	.908 .898 .891 .895 .896 .995 .909 .921 .910	.906 .907 .900 .900 .908 .910 .914 .928 .943	.981 .917 .910 .912 .907 .907 .917 .928 .943	.856 .853 .857 .853 .863 .863 .986 .986	.882 .877 .870 .873 .870 .889 .892 .909 .933	.880 .873 .880 .876 .883 .091 .994 .912 .931	.885 .885 .885 .895 .897 .913 .933 .948	.901 .896 .896 .896 .904 .904 .919 .935	.911 .904 .907 .904 .910 .910 .922 .938	.837 .836 .834 .844 .897 .862 .886 .910	.861 .855 .857 .855 .862 .870 .874 .894 .916	.870 .863 .865 .866 .867 .875 .875 .879 .996 .918	.880 .874 .875 .883 .883 .884	.890 .662 .883 .883 .890 .891 .903 .910	888888888888888888888888888888888888888
3.59 8.09 8.38 8.38 8.38 8.38 8.38 8.38 9.38 9.3	.872 .867 .867 .868 .880 .893 .898 .919 .937 .960	.888 .883 .878 .879 .879 .886 .897 .996 .954	.901, .896 .886 .886 .893 .901 .903 .921 .948 .975	.902 .898 .891 .895 .895 .995 .909 .921 .910 .975 .975	.906 .907 .900 .902 .900 .908 .914 .928 .943 .955	981 917 910 912 907 907 917 928 943 959	853 857 853 853 853 853 853 853 853 853 853 853	.882 .877 .870 .873 .870 .880 .889 .992 .909	.880 .873 .880 .876 .883 .091 .991 .933	.885 .885 .885 .895 .897 .913 .948 .948	.901 .896 .896 .896 .904 .904 .919	.911 .904 .907 .899 .904 .910 .910 .938 .938 .938	.837 .830 .836 .834 .844 .867 .866 .910 .911 .915	.861 .875 .877 .875 .870 .874 .894 .916 .934	.870 .863 .866 .866 .867 .875 .875 .918 .935 .918	.880 .874 .872 .875 .883 .884 .900 .937	.890 .662 .883 .862 .890 .991 .903	888888888888888888888888888888888888888
3.50 3.50 3.50 3.50 3.50 3.50 3.50 3.50	.872 .867 .867 .868 .889 .899 .995 .957 .960 .961	\$88 \$83 \$79 \$86 \$30 \$30 \$30 \$30 \$30 \$30 \$30 \$30 \$30 \$30	.901, .896 .886 .886 .893 .901 .903 .921 .948 .979 .979	.902 .898 .891 .899 .893 .896 .909 .921 .913 .973 .979	.906 .907 .900 .902 .908 .914 .928 .943 .955 .979	.921 .917 .910 .912 .907 .907 .917 .928 .943 .959 .959	.856 .853 .857 .853 .863 .863 .986 .986	.882 .877 .870 .873 .870 .880 .889 .999 .933 .946	.880 .873 .880 .876 .883 .091 .994 .918 .946	.885 .885 .885 .895 .897 .913 .933 .948	.901 .896 .896 .896 .904 .904 .919 .935 .950	.911 .904 .907 .904 .916 .916 .918 .918 .918 .918 .916	.837 .830 .836 .834 .844 .862 .886 .910 .915 .951	.861 .875 .877 .875 .870 .874 .894 .916 .934	.870 .863 .865 .867 .875 .875 .875 .918 .935 .918	.880 .872 .874 .872 .875 .883 .984 .900 .993 .917	.890 .662 .883 .883 .890 .891 .903 .910	8.88 8.88 8.89 9.99 9.99 9.99 9.99
3.59 3.84 4.09 4.84 4.58 4.34 4.34 4.34 4.34 4.34 4.34	.872 .867 .867 .868 .880 .893 .898 .919 .937 .960	888 887 887 887 887 887 887 887 887 887	901. 898. 886. 886. 889. 903. 91. 91. 91. 91. 91. 91. 91. 91. 91. 91	.902 .898 .891 .895 .895 .999 .944 .975 .979	.906 .909 .909 .908 .914 .983 .943 .953 .959 .979 .979	981 917 910 912 907 907 917 928 943 959	\$5555555555555555555555555555555555555	.882 .877 .870 .873 .870 .889 .932 .946 .954 .954	.880 .873 .880 .876 .883 .091 .918 .933 .946 .946	.882 .883 .883 .883 .895 .933 .944 .976 .976	.013 888 888 888 888 888 888 888 888 888 8	.911 .904 .907 .904 .916 .916 .918 .918 .918 .918 .916	.837 .830 .836 .834 .844 .867 .866 .910 .911 .915	.861 .855 .857 .856 .870 .874 .894 .914 .934 .934 .954	863 866 867 879 893 893 893 993 993 993	.880 .872 .874 .872 .875 .883 .900 .993 .917 .910	.890 .883 .883 .893 .990 .994 .942 .967 .972	8 .8 .8 .8 .8 .8 .8 .8 .8 .8 .8 .8 .8 .8
3.584 3.844 3.	\$57 858 859 95 55 55 55 55 55 55 55 55 55 55 55 5	888 887 887 887 887 887 887 887 887 887	901. 898. 886. 886. 889. 903. 91. 91. 91. 91. 91. 91. 91. 91. 91. 91	.902 .893 .895 .895 .895 .905 .909 .901 .905 .909 .900 .900 .900 .900 .900 .900	.906 .907 .900 .908 .908 .914 .983 .943 .979 .979	.91. .91. .91. .91. .92. .93. .93. .93. .93. .93. .93. .93	\$.884 .877 .870 .870 .889 .933 .946 .946 .954 .954 .958	.880 .873 .880 .876 .883 .091 .912 .914 .914 .946 .976	888 888 888 888 888 888 888 888 888 88	.01.896 .896 .896 .896 .907 .907 .907 .907 .908	.911 .904 .905 .904 .916 .916 .916 .916 .916 .916 .916 .916	.837 .830 .836 .834 .844 .862 .886 .910 .915 .951	.861 .877 .877 .862 .874 .916 .934 .918 .922 .964	870 863 864 867 875 896 918 935 954 957 957	.880 .874 .875 .885 .900 .993 .917 .910 .957 .957	.890 .883 .883 .890 .903 .924 .940 .942 .942 .942	88888888888888888888888888888888888888
3.59 4.09 4.84 5.84 5.84 5.84 5.84 5.84 5.84 5.84	######################################	88.88.88.88.88.88.88.88.88.88.88.88.88.	.901, .898 .886 .893 .903 .903 .903 .903 .903 .903 .903 .9	.902 .898 .891 .893 .895 .909 .944 .909 .979 .979 .979 .983 .989	.906 .909 .909 .908 .914 .983 .943 .953 .959 .979 .979	.91. .91. .91. .91. .91. .91. .91. .91.	<i>************************************</i>	.882 .877 .870 .870 .880 .889 .933 .940 .940 .976 .979 .988	.880 .873 .880 .876 .883 .091 .934 .934 .936 .936 .976	888 889 889 889 889 889 889 889 889 889	.01.356 .856 .856 .856 .856 .857 .857 .858 .858 .858 .858 .858 .858	.914 .904 .905 .904 .910 .910 .910 .910 .910 .910 .910 .910	.837 .830 .836 .834 .847 .866 .910 .931 .931 .931 .951 .951	861 857 857 858 870 874 874 915 915 915 915 915 915 915 915 915	870 863 867 867 867 867 867 867 867 867 867 867	.880 .874 .875 .885 .900 .993 .917 .910 .955 .957 .957	.890 .883 .883 .893 .903 .904 .940 .942 .942 .942 .944 .964	8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
33.89 33.89 33.83	## 867 867 868 869 869 869 869 869 869 869 869 869	88.85.85.85.85.85.85.85.85.85.85.85.85.8	.901 .856 .886 .886 .893 .901 .903 .910 .910 .910 .910 .910 .910 .910 .910	.902 .893 .897 .893 .896 .909 .944 .959 .959 .959 .959 .959 .959	.906 .909 .908 .908 .914 .988 .943 .975 .979 .979 .979 .988	.917 .912 .917 .917 .917 .917 .943 .943 .955 .960 .979 .960 .979 .968	<i>************************************</i>	.882 .877 .870 .873 .889 .889 .993 .946 .949 .954 .954 .954 .954 .958 .969	.880 .873 .880 .883 .891 .936 .936 .936 .956 .959 .959	888 888 888 888 888 888 888 888 888 88	.001 .866 .866 .866 .904 .935 .935 .956 .956 .956 .956 .956 .956 .956 .95	.911 .904 .905 .904 .910 .910 .910 .916 .916 .916 .916 .916 .916 .916 .916	.837 .830 .834 .834 .857 .866 .910 .915 .951 .966 .915 .965	861 857 858 858 858 858 858 858 858 858 858	863 866 867 8796 975 975 975 975 975 975 975 975 975 975	.880 .871 .875 .883 .800 .935 .975 .975 .975 .975 .975	.890 .883 .883 .890 .993 .944 .942 .942 .944 .945 .946 .946	
3.8.9 3.8.9 3.8.9 4.5.3.8 4.5.3.8 4.3.3.4 112.3.3 112.3.3 113.3 1.3 1	######################################	883845885855555888888888888888888888888	.901 .898 .888 .886 .893 .948 .979 .963 .963 .963 .963 .963 .963 .963 .96	.902 .863 .865 .865 .865 .865 .865 .865 .865 .865	.945 .906 .908 .908 .914 .943 .943 .955 .979 .979 .978 .988 .988	917 912 917 917 917 917 917 917 917 917 917 917	<i>6.65</i> 6.68 6.88	.888 .877 .873 .870 .889 .933 .946 .959 .959 .959 .959 .959	.890 .873 .866 .863 .893 .915 .916 .916 .916 .916 .916 .916 .916 .916	888 883 883 883 883 883 883 883 883 883	.00.00 .00.00 .00.00 .00.00 .00.00 .00.00	.914 .909 .904 .919 .919 .919 .919 .919 .919 .919 .91	.837 .830 .836 .834 .857 .866 .931 .945 .951 .965 .971	.861 .875 .875 .862 .870 .974 .934 .934 .934 .972 .964 .977 .984 .986	863 866 865 859 859 855 855 855 855 855 855 855 85	89 89 89 89 89 89 89 89 89 89 89 89 89 8	.890 .882 .883 .890 .994 .940 .940 .940 .940 .940 .940 .9	.EEEEE
33444555678944344444444444456678944444455667894444445556789444444444444444444444444444444444444	######################################	883 879 886 887 887 888 888 888 888 888 888 888	901 888 888 888 888 893 903 903 903 903 903 903 903 903 903 9	.902 .893 .893 .893 .895 .909 .921 .939 .939 .939 .939 .939	.945 .906 .908 .908 .908 .914 .943 .955 .975 .976 .988 .993	\$1.70 \$9.70	\$.882 .877 .873 .870 .880 .880 .999 .933 .944 .954 .954 .968 .969 .969	.890 .873 .866 .863 .891 .915 .916 .916 .916 .956 .979 .989 .989 .998	88453888555333884456688865888	.01.36 88.86 88 88.86 88 88 88 88 88 88 88 88 88 88 88 88 8	.911 .904 .905 .904 .913 .913 .915 .915 .916 .916 .916 .916 .916 .916 .916 .916	.837 .836 .834 .834 .857 .866 .911 .915 .961 .975 .987 .988 .988 .988	861 .875 .870 .870 .874 .914 .914 .914 .914 .914 .914 .914 .91	850 850 850 850 850 850 850 850 850 850	.880 .872 .873 .883 .893 .993 .997 .997 .997 .997 .997 .987 .988	\$90 \$88 \$83 \$90 \$95 \$95 \$95 \$95 \$95 \$95 \$95 \$95 \$95 \$95	.88 .88 .88 .88 .89 .99 .99 .99 .99 .99
334445556789102453344445556789102453344445556789102453344444555678910245334444445	######################################	8838-4-6-8-6-8-8-1-8-4-5-8-8-8-8-8-8-8-8-8-8-8-8-8-8-8-8-8	901 888 888 888 889 979 970 980 976 989 978 978 978 978 978 978 978 978 978	.902 .893 .893 .893 .893 .909 .914 .975 .979 .979 .989 .989 .989 .989	.947 .902 .902 .904 .904 .903 .904 .903 .904 .903 .905 .909 .909 .909 .909 .909 .909 .909	917 917 917 917 917 917 917 917 917 917	<i>\$5555555558555555555555555555555555555</i>	884 657 653 658 658 658 658 658 658 658 658 658 658	.890 .873 .866 .883 .974 .976 .976 .976 .976 .976 .976 .978 .978 .979	884555555333844555845559455594555	.01.36 860.864.95 964.95 965.964.95 965.964.95 965.964.95 965.964.95 965.964.95	.914 .959 .904 .930 .930 .936 .936 .956 .956 .958 .954 .954	.837 .836 .834 .857 .866 .930 .931 .955 .966 .971 .965 .968 .968	.861 .875 .875 .876 .876 .916 .914 .916 .914 .916 .914 .916 .916 .916 .916 .916 .916 .916 .916	\$66688655886555555555555555555555555555	890 674 675 883 893 993 993 993 993 993 993 993 993	890 882 883 893 993 994 967 974 966 986 986 987 986 986 986 986 986 986 986 986 986 986	
33444555678944344444444444456678944444455667894444445556789444444444444444444444444444444444444	######################################	883 879 886 887 887 888 888 888 888 888 888 888	901 888 888 888 888 893 903 903 903 903 903 903 903 903 903 9	.902 .893 .893 .893 .895 .909 .921 .939 .939 .939 .939 .939	.945 .906 .908 .908 .908 .914 .943 .955 .975 .976 .988 .993	\$1.70 \$9.70	\$.882 .877 .873 .870 .880 .880 .999 .933 .944 .954 .954 .968 .969 .969	.890 .873 .866 .863 .891 .915 .916 .916 .916 .956 .979 .989 .989 .998	88453888555333884456688865888	.01.36 88.86 88 88.86 88 88 88 88 88 88 88 88 88 88 88 88 8	.911 .904 .905 .904 .913 .913 .915 .915 .916 .916 .916 .916 .916 .916 .916 .916	.837 .836 .834 .834 .857 .866 .911 .915 .961 .975 .987 .988 .988 .988	861 .875 .870 .870 .874 .914 .914 .914 .914 .914 .914 .914 .91	850 850 850 850 850 850 850 850 850 850	.880 .872 .873 .883 .893 .993 .997 .997 .997 .997 .997 .987 .988	\$90 \$88 \$83 \$90 \$95 \$95 \$95 \$95 \$95 \$95 \$95 \$95 \$95 \$95	888888

TABLE I.- LOCAL VELOCITY RATIO, U/V - Concluded

(c) The 1-series spinner, no cowl

Radial station, in.	M=0.15	M=0.20	M=0 • 40	M=0.50	M=0.60	M =0.70	M=0.80
3.44 3.69 3.94 4.19 4.44 4.94	1.071 1.070 1.063 1.049 1.042	1.079 1.078 1.068 1.063 1.057 1.037	1.088 1.082 1.077 1.062 1.059 1.043	1.092 1.095 1.079 1.067 1.063 1.046	1.102 1.102 1.089 1.076 1.071 1.059	1.108 1.109 1.094 1.081 1.076 1.064	1.124 1.124 1.107 1.092 1.088 1.071
5.44 5.94 6.44 7.44 8.44 9.44	1.020 1.019 1.013 1.005 •997 1.003	1.030 1.029 1.019 1.018 1.012	1.035 1.028 1.020 1.014 1.015 1.008	1.038 1.036 1.024 1.014 1.014	1.050 1.044 1.031 1.023 1.023 1.021	1.052 1.046 1.034 1.027 1.027 1.025	1.065 1.055 1.043 1.032 1.033 1.035
10.44 12.44 14.44 16.44 18.44	1.002 1.001 •999 •998 •997	1.005 1.004 .997 .996	1.005 1.001 1.005 .999	1.006 1.004 1.003 -997 -996	1.011 1.004 1.006 1.002 1.002	1.013 1.005 1.007 1.003 1.002	1.013
20.44 22.44 24.44 26.44 28.44	•997 •899 1•003 •995 1•002	1.000 .999 1.009 1.003 1.008	1.000 .997 1.001 1.000 1.001	1.004 1.001 1.004 1.002 1.001	1.004 1.001 1.002 1.005 1.004	1.005 1.002 1.003 1.003	•999
30.44 32.44	1.002	1.008	1.003 1.004	1.001	1.003 1.008	1.003	1.001

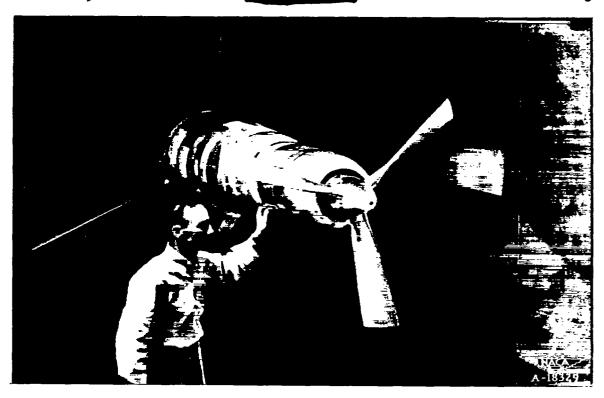


Figure 1.- The model mounted on the 1000-horsepower propeller dynamometer in the 12-foot pressure wind tunnel.

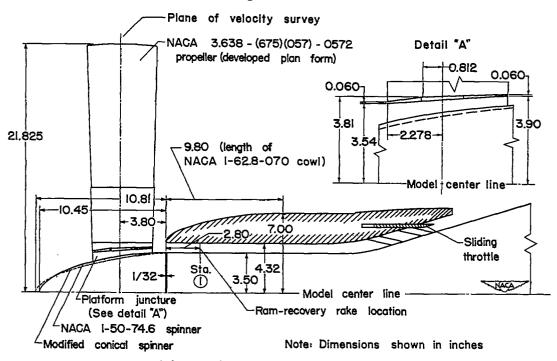


Figure 2.- Model arrangement.



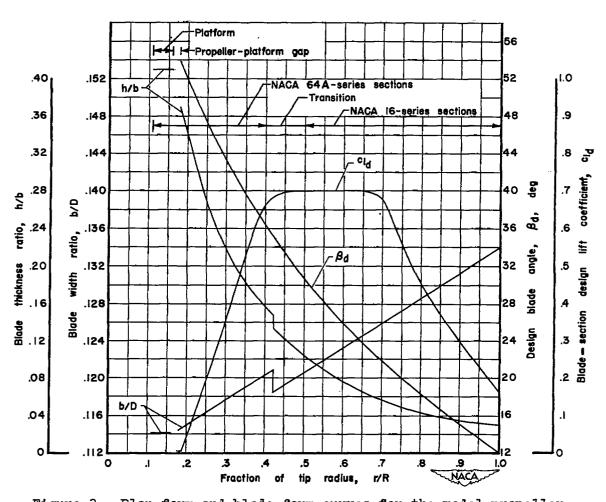


Figure 3.- Plan-form and blade-form curves for the model propeller having the designation NACA 3.638-(675)(057)-0572.

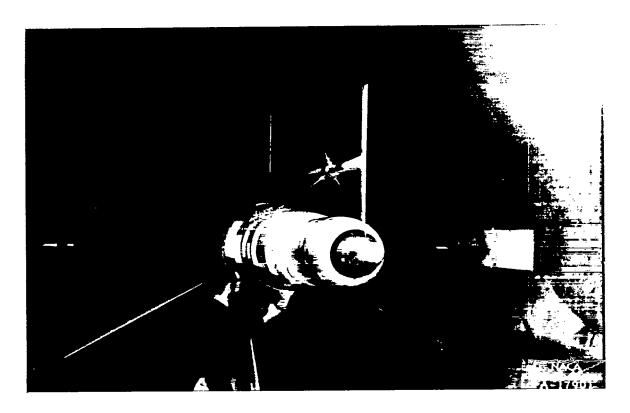


Figure 4.- Photograph of the survey rake.

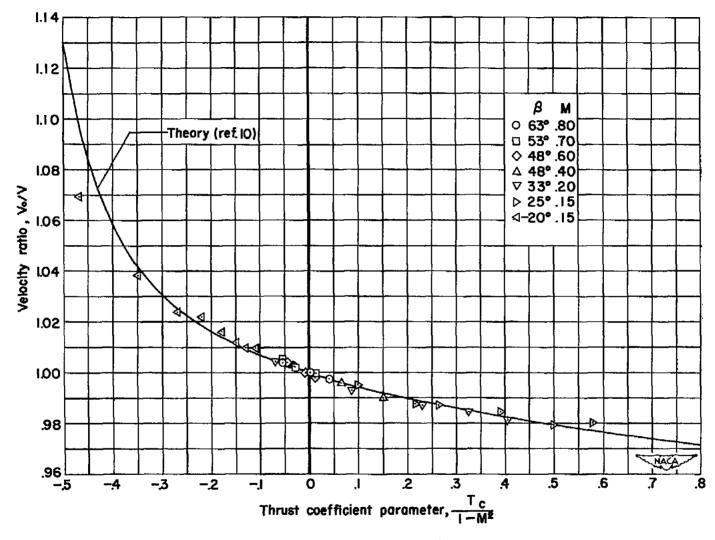


Figure 5.- Tunnel-wall-interference correction for a 3.6-foot-diameter propeller in the Ames 12-foot pressure wind tunnel.

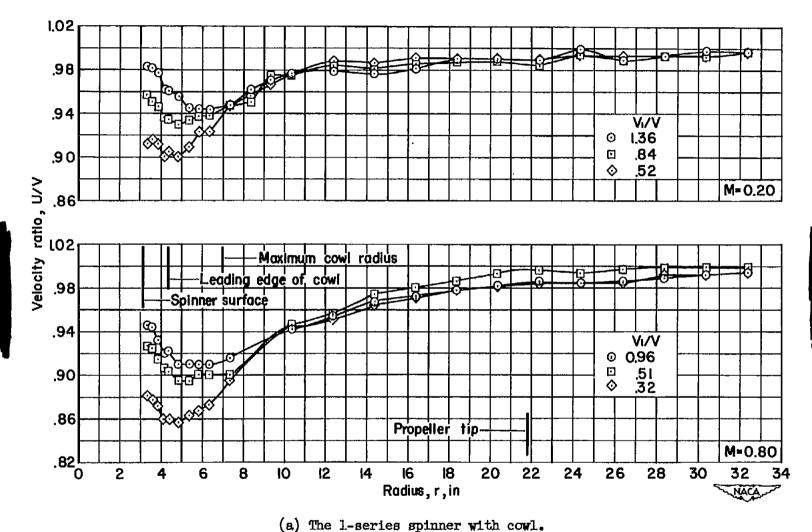
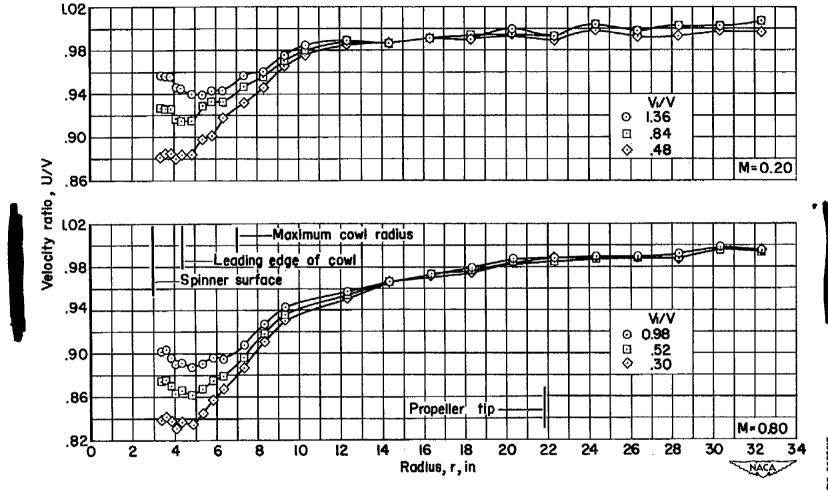
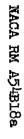


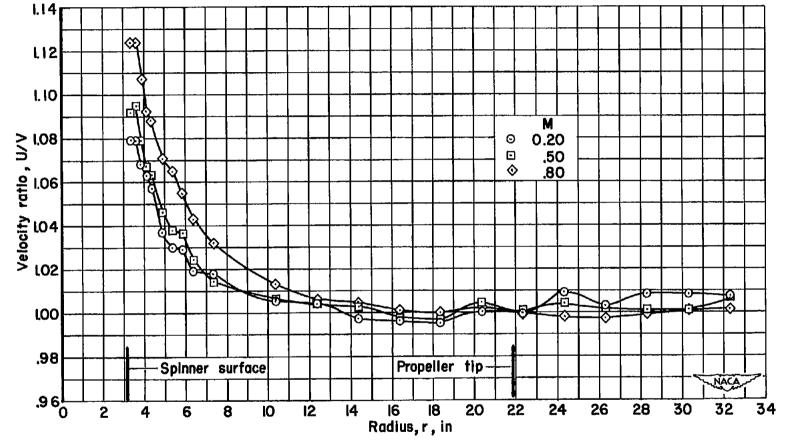
Figure 6.- Typical radial distributions of the local velocity ratio in the plane of the propeller.



(b) Modified conical spinner with cowl.

Figure 6.- Continued.





(c) The 1-series spinner, no cowl.

Figure 6.- Concluded.

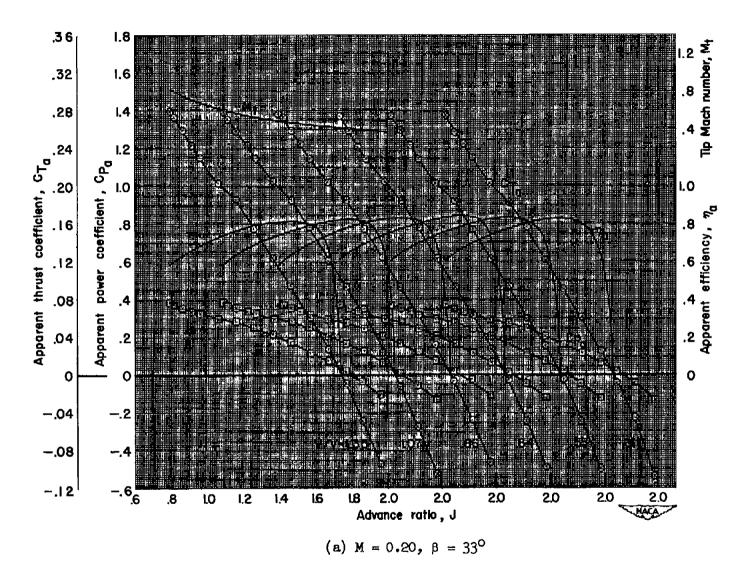
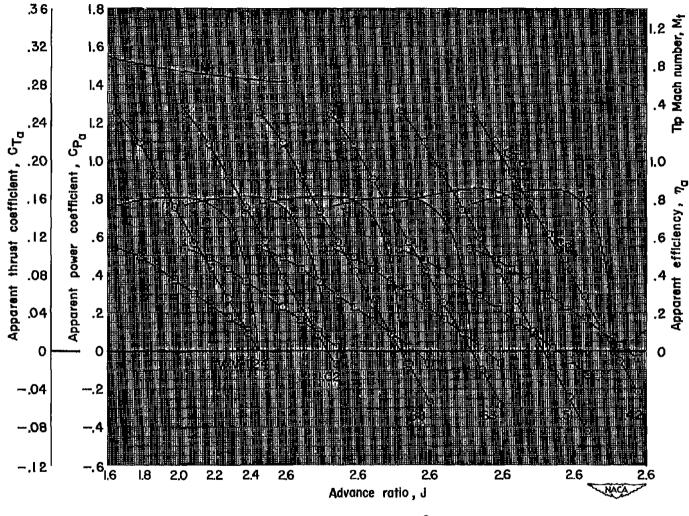
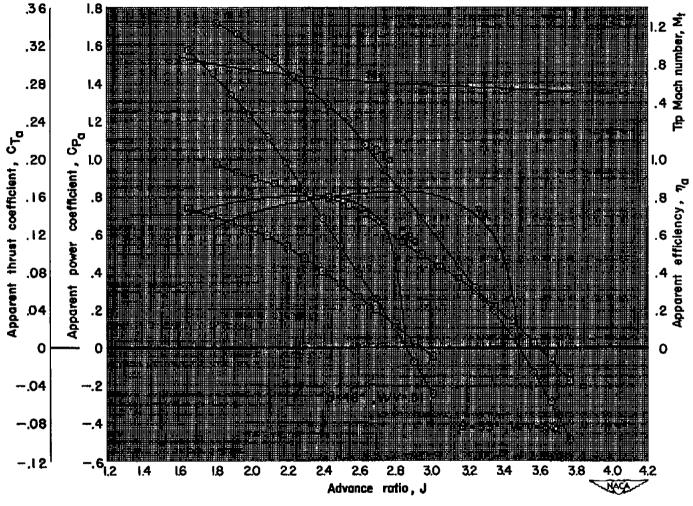


Figure 7.- Characteristics of the propeller with the 1-series spinner and cowl.



(b) M = 0.40, $\beta = 43^{\circ}$

Figure 7.- Continued.



(c) M = 0.40, $\beta = 48^{\circ}$ and 53°

Figure 7.- Continued.

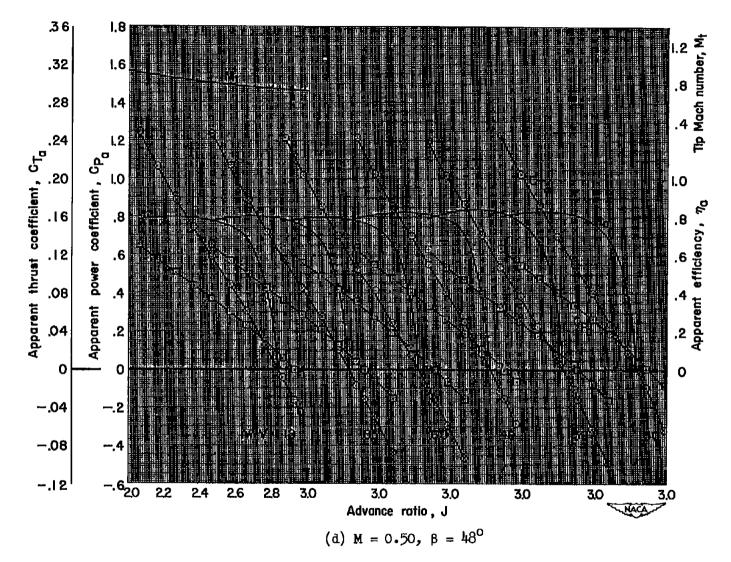


Figure 7.- Continued.

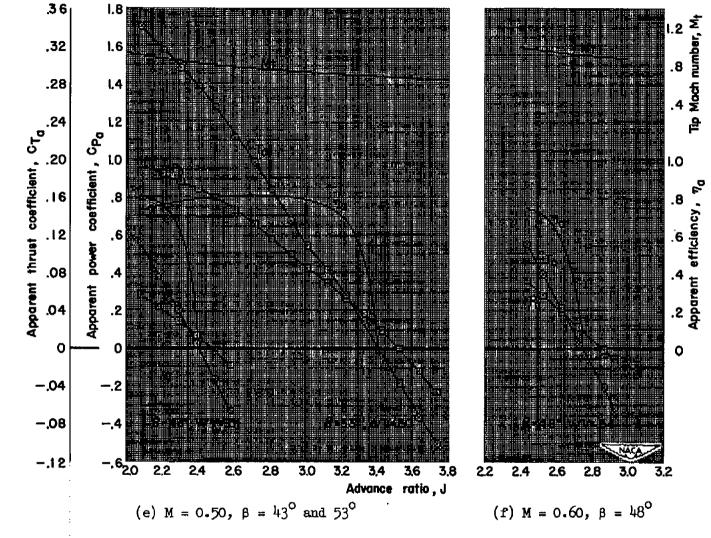
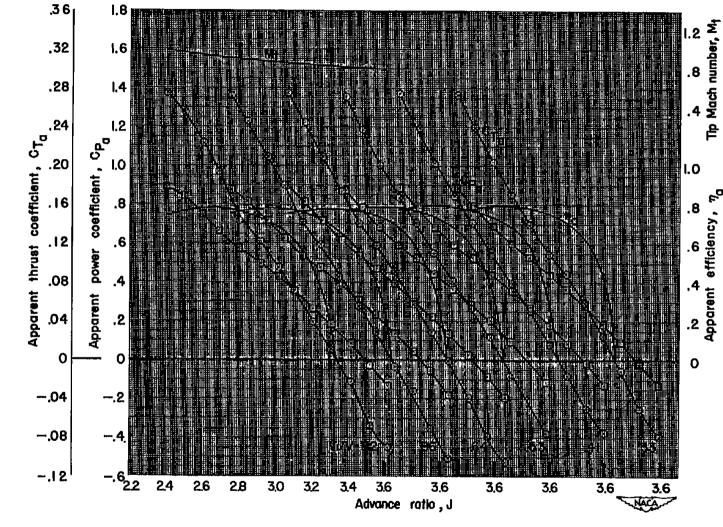
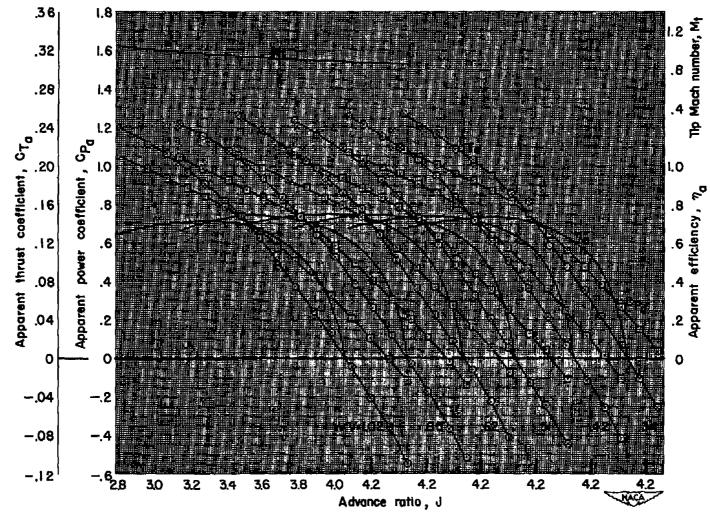


Figure 7.- Continued.



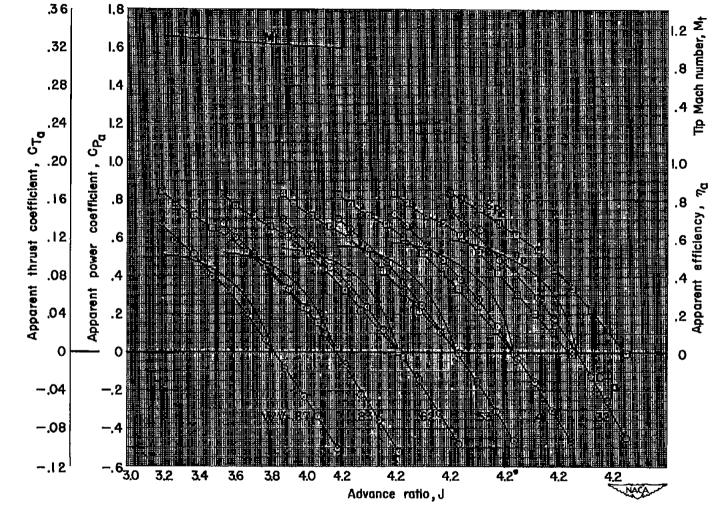
(g) M = 0.60, $\beta = 53^{\circ}$

Figure 7.- Continued.



(h) M = 0.70, $\beta = 58.5^{\circ}$

Figure 7.- Continued.



(i) M = 0.80, $\beta = 58.5^{\circ}$

Figure 7.- Concluded.

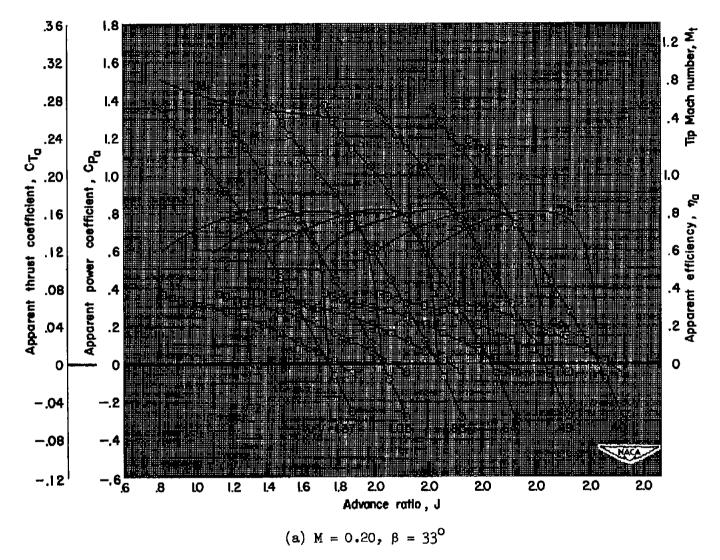
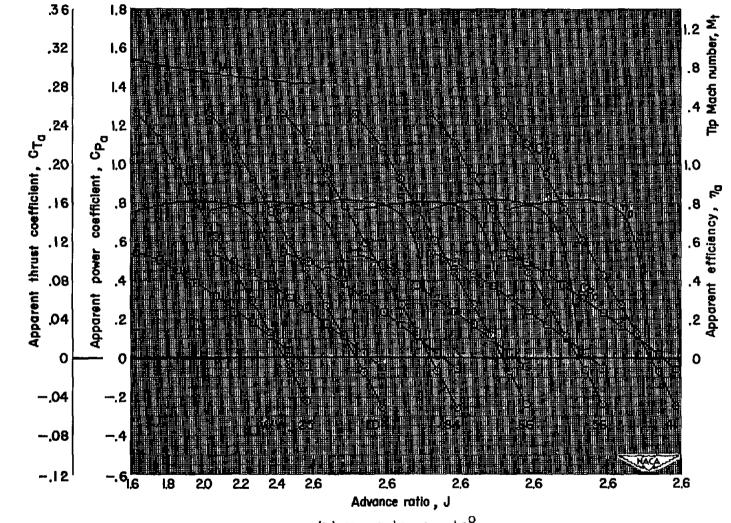


Figure 8.- Characteristics of the propeller with the modified conical spinner and cowl.



(b) M = 0.40, $\beta = 43^{\circ}$

Figure 8.- Continued.

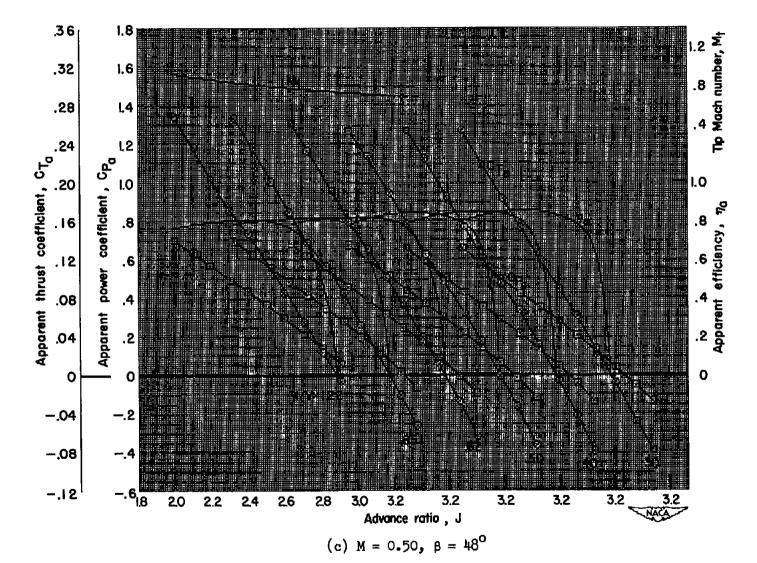
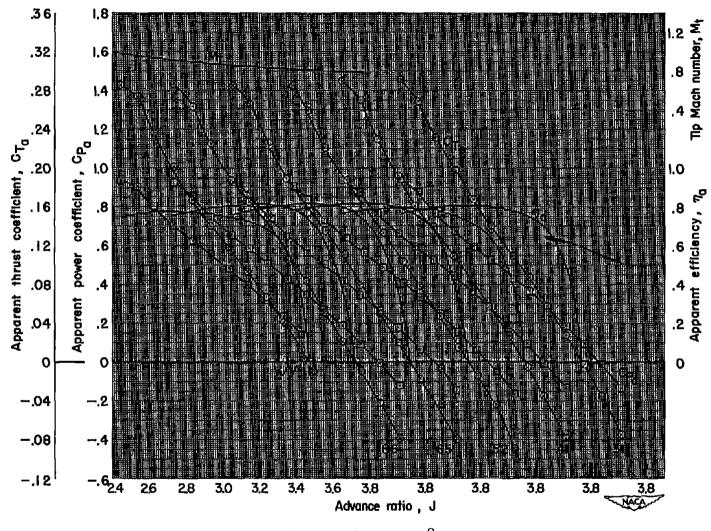
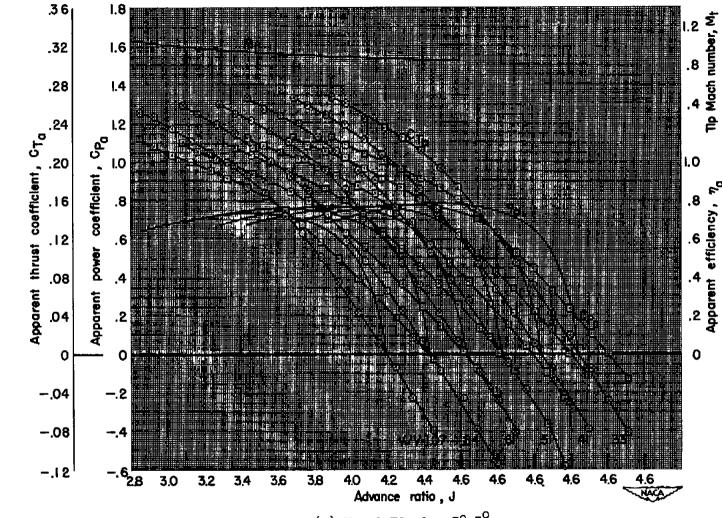


Figure 8.- Continued.



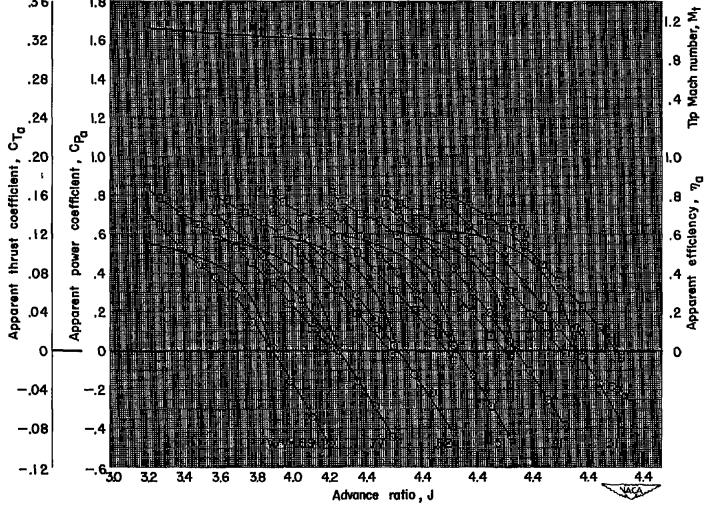
(d) M = 0.60, $\beta = 53^{\circ}$

Figure 8.- Continued.



(e) M = 0.70, $\beta = 58.5^{\circ}$

Figure 8.- Continued.



(f) M = 0.80, $\beta = 58.5^{\circ}$

Figure 8.- Concluded.

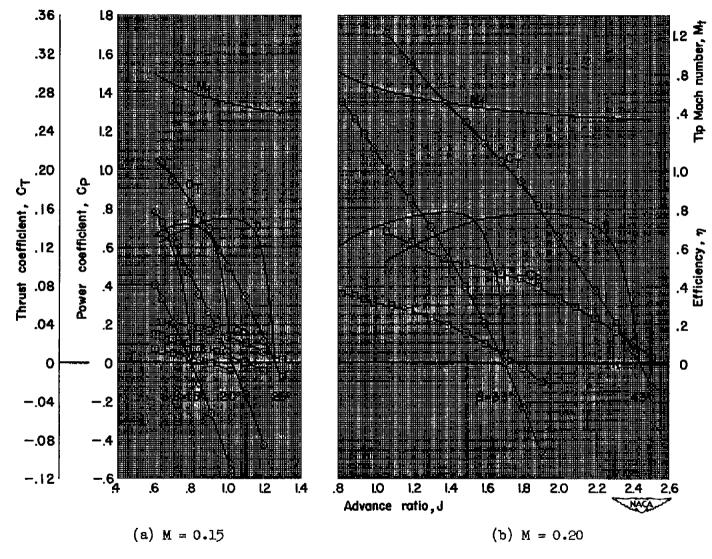
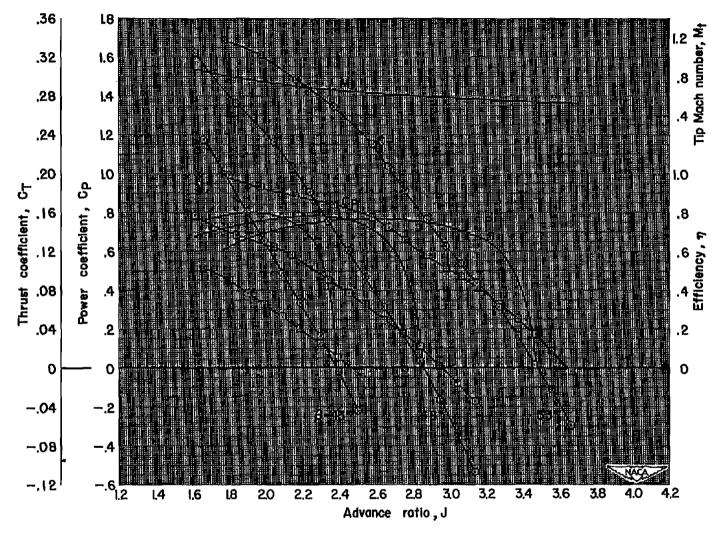
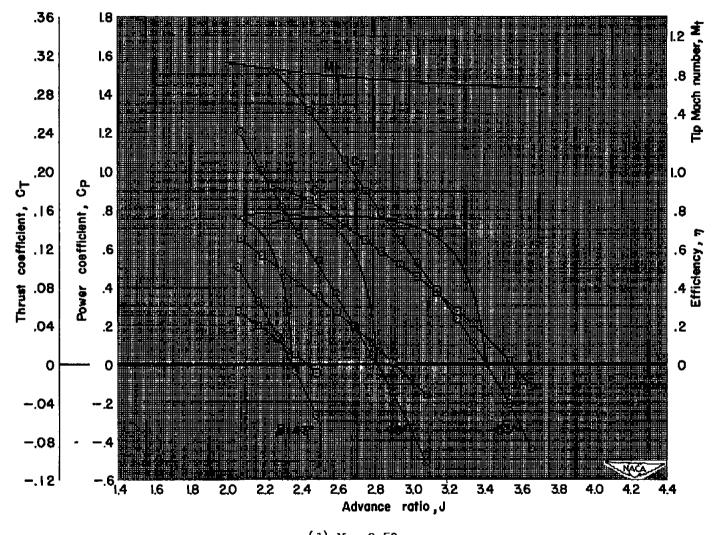


Figure 9.- Characteristics of the isolated propeller-spinner combination.



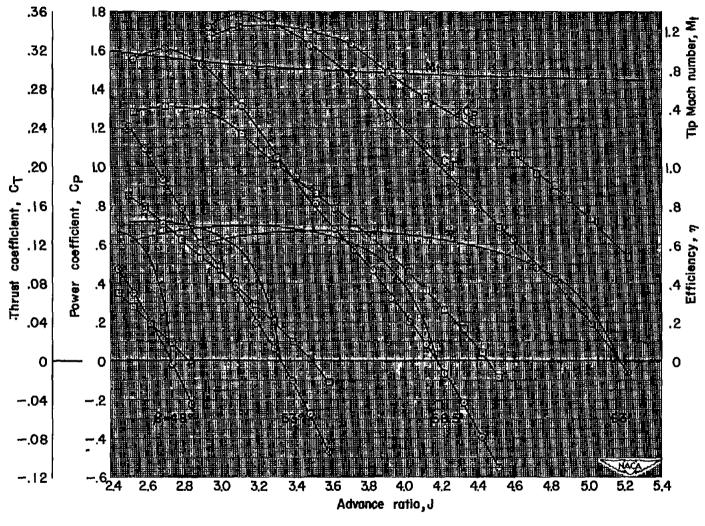
(e) M = 0.40

Figure 9.- Continued.



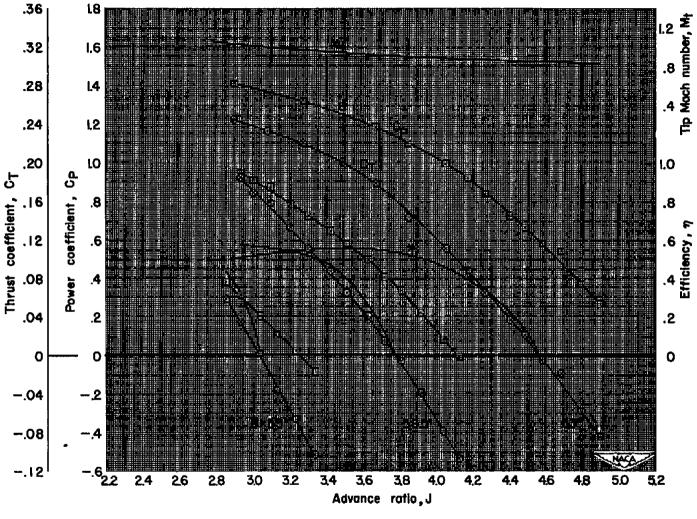
(d) M = 0.50

Figure 9.- Continued.



(e) M = 0.60

Figure 9.- Continued.



(f) M = 0.70

Figure 9.- Continued.

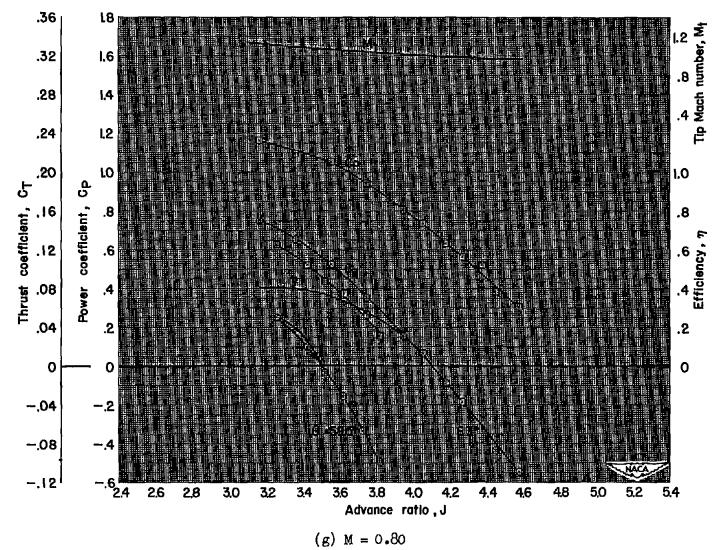


Figure 9.- Concluded.

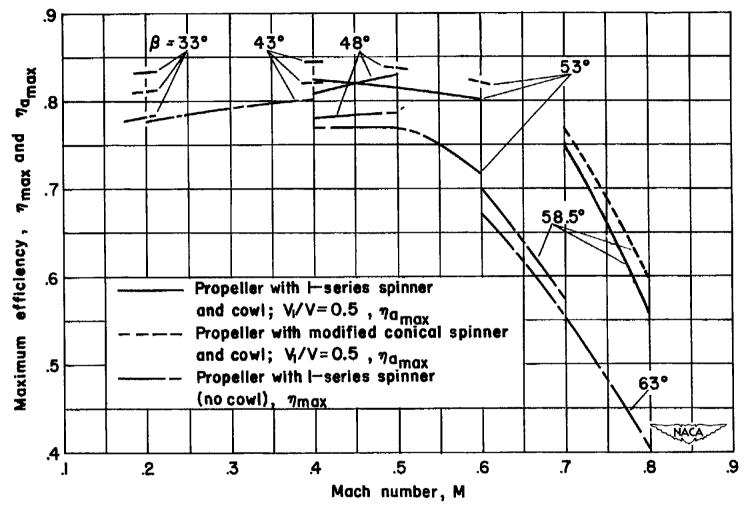


Figure 10.- Comparison of the maximum efficiency of the propeller with and without the cowl.

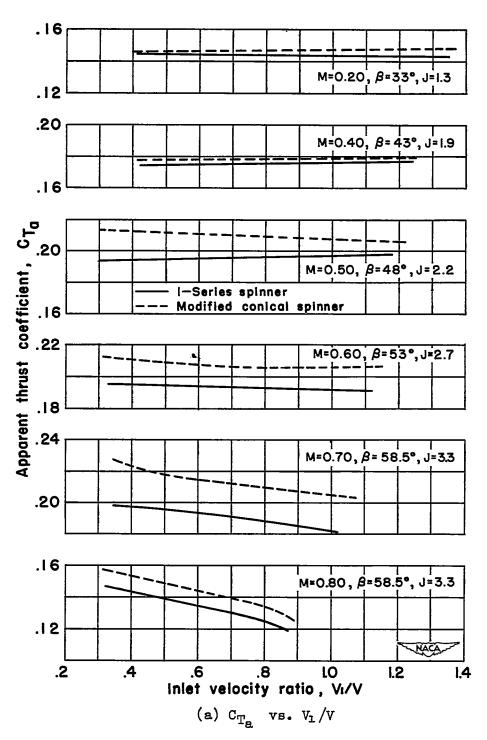


Figure 11.- Typical effect of inlet velocity ratio on the apparent thrust and power coefficients of the propeller.



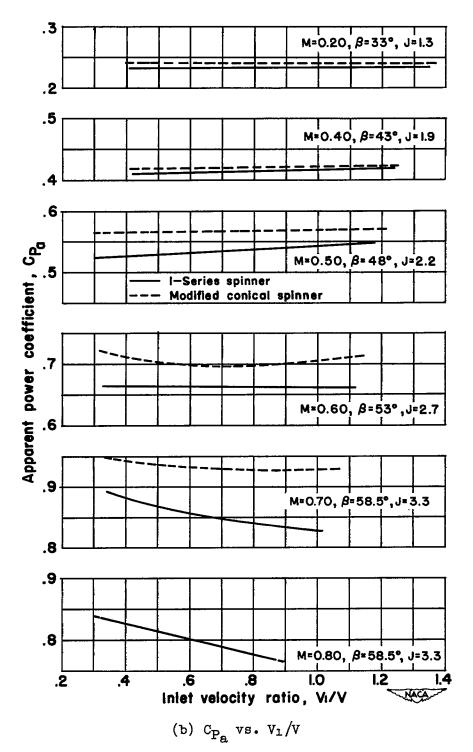


Figure 11.- Concluded.

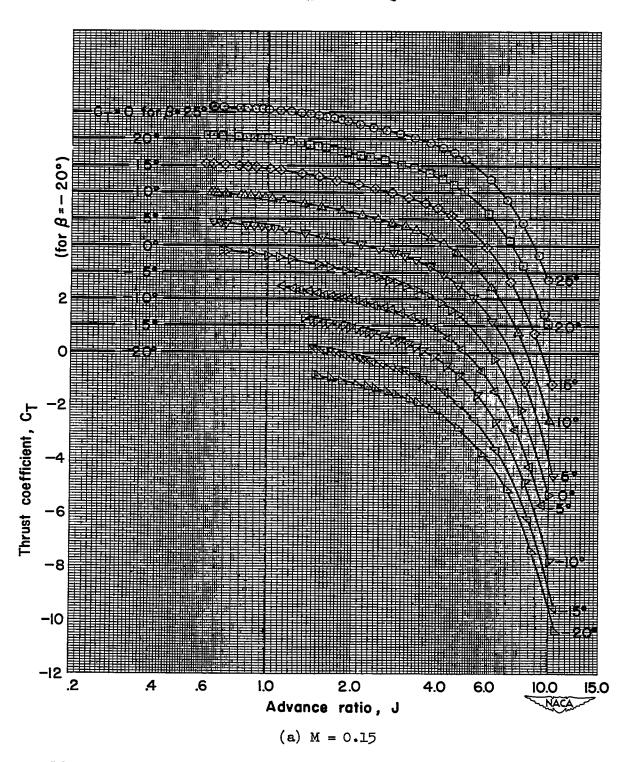
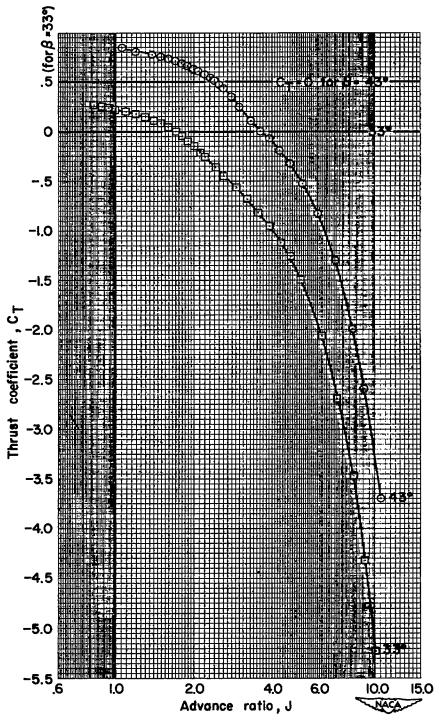


Figure 12.- Negative thrust coefficients for the isolated propellerspinner combination.







(b) M = 0.20

Figure 12.- Continued.





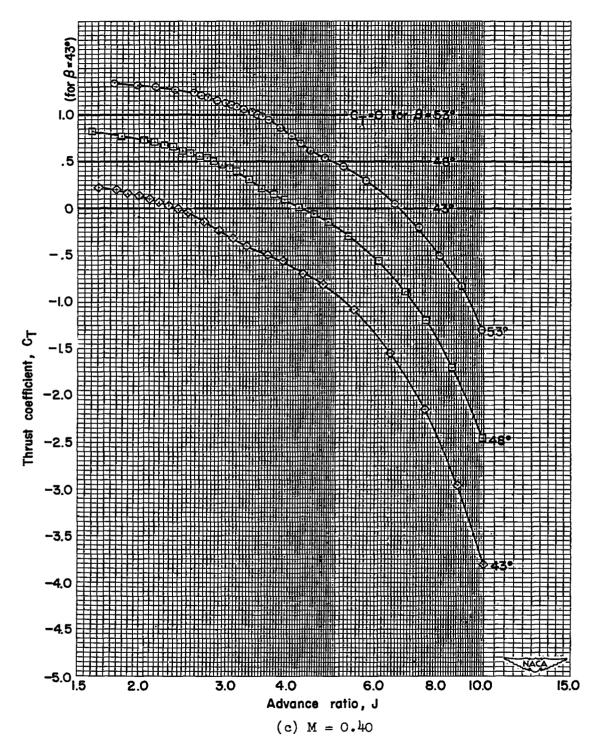


Figure 12.- Continued.



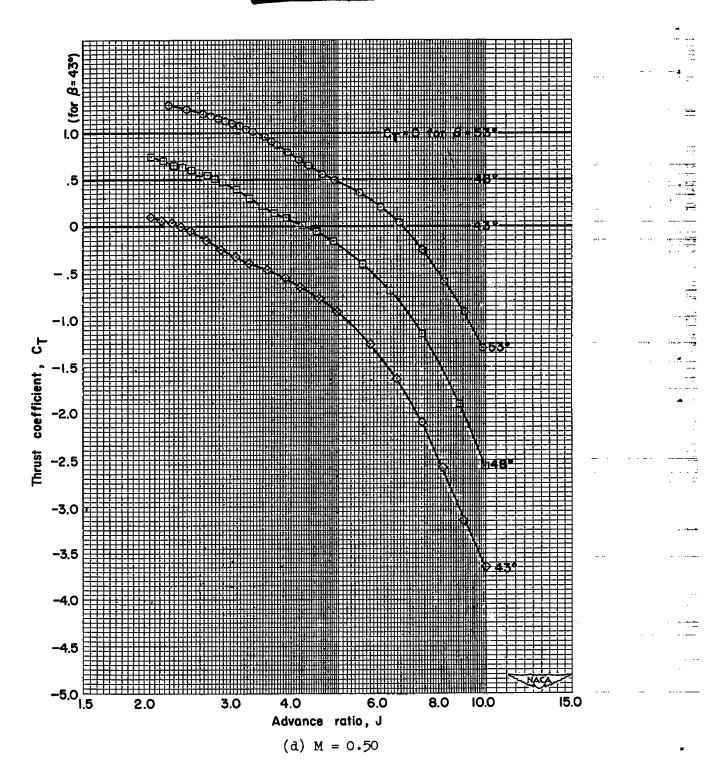
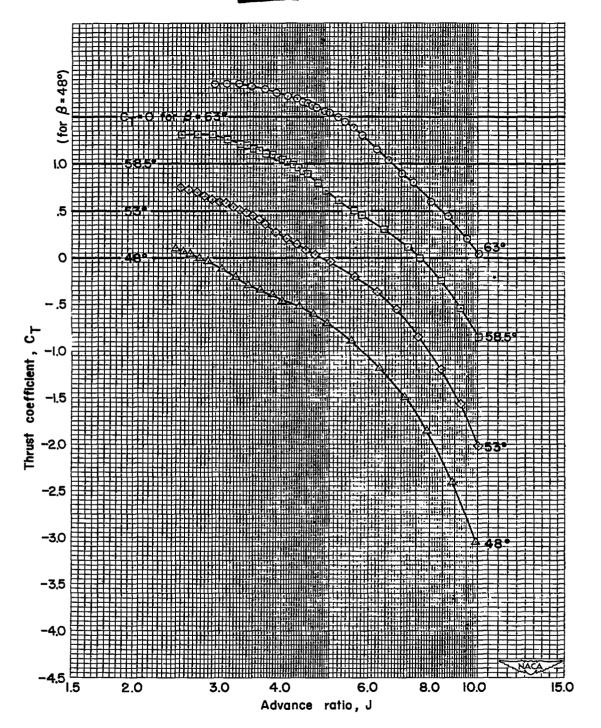


Figure 12.- Continued.







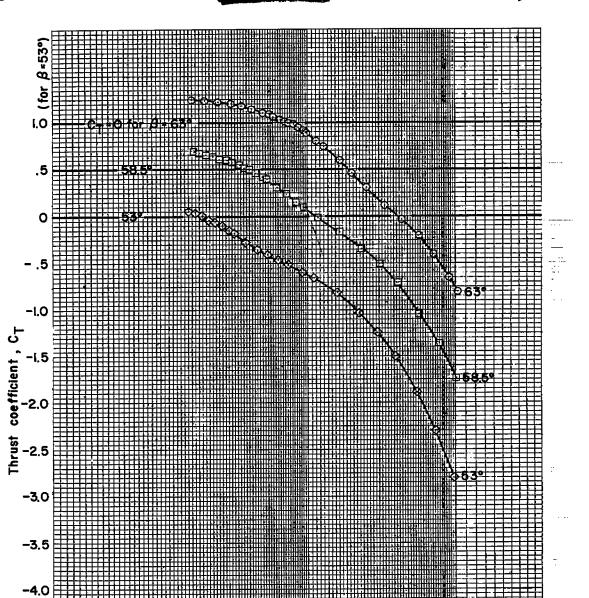
(e) M = 0.60

Figure 12.- Continued.



-4.5

2.0



(f) M = 0.70

Advance ratio, J

4.0

3.0

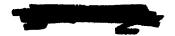
8.0

6.0

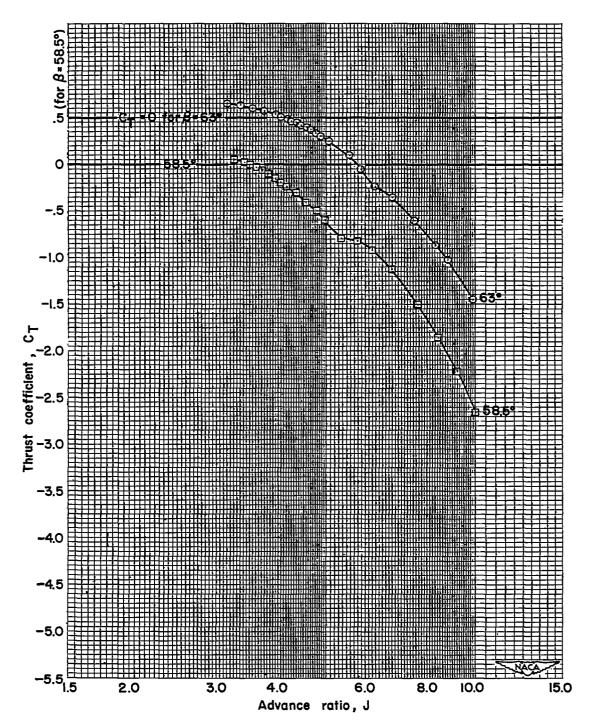
10.0

15.0

Figure 12.- Continued.







(g) M = 0.80

Figure 12.- Concluded.



.2

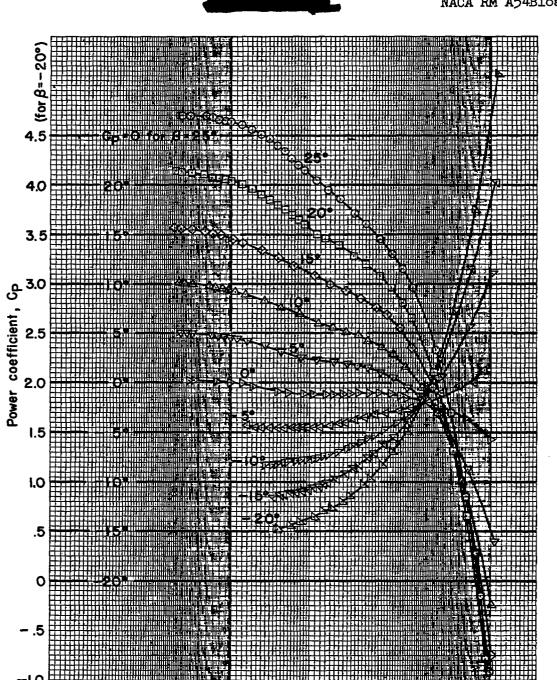


Figure 13.- Power coefficients for the isolated propeller-spinner combination in negative thrust.

(a) M = 0.15

2.0

Advance ratio, J

4.0

6.0 8.0 10.0

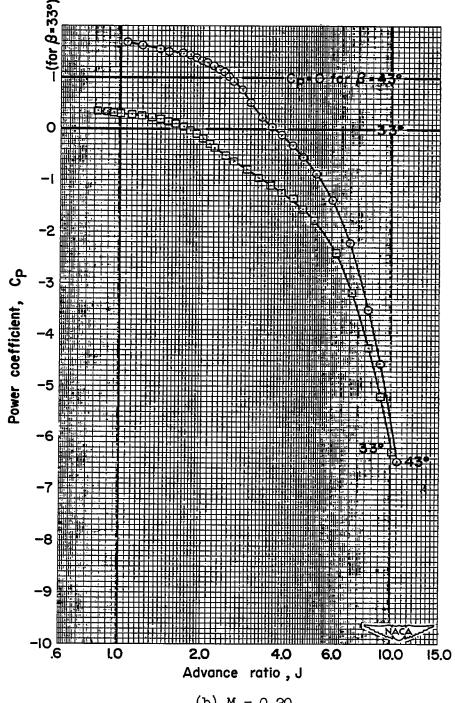
15.0

1.0

8,

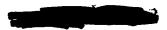
.6

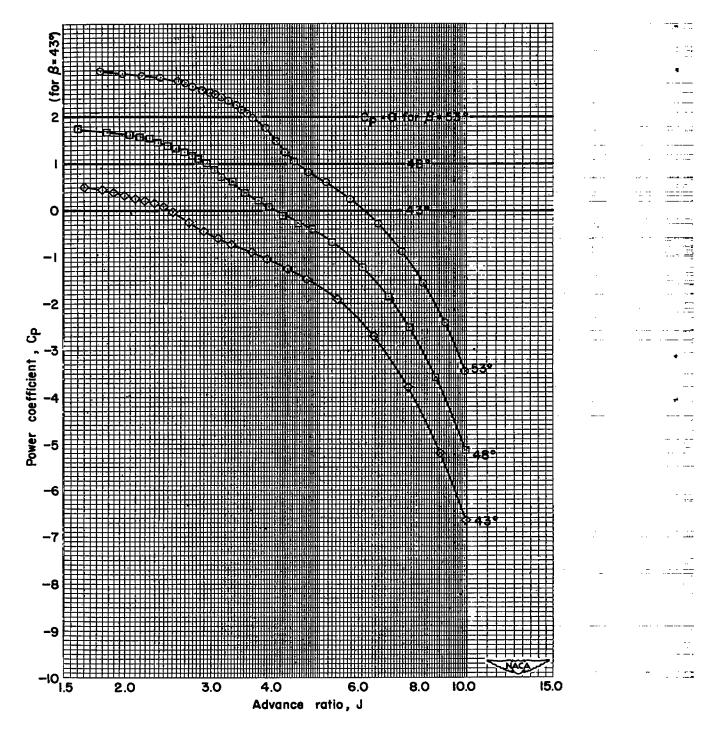




(b) M = 0.20

Figure 13.- Continued.





(e) M = 0.40

Figure 13.- Continued.



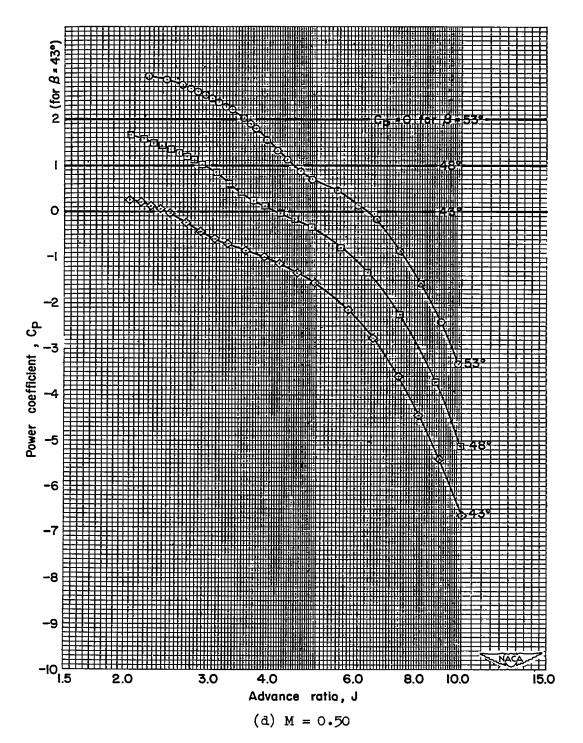
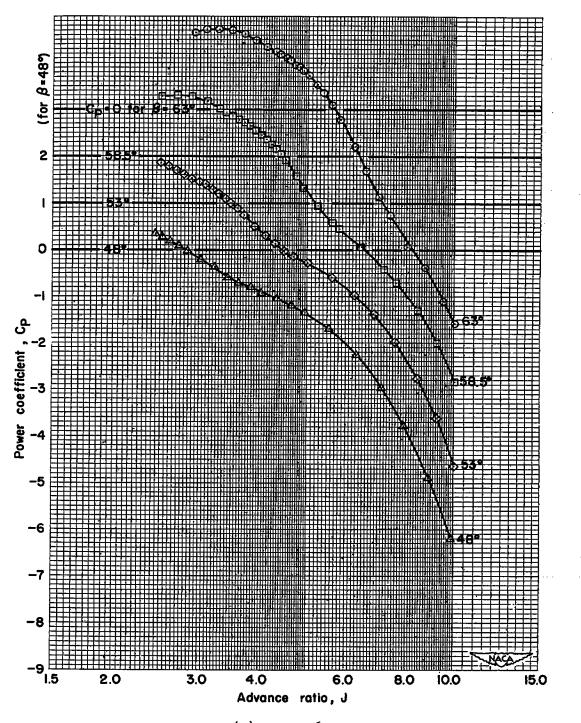


Figure 13.- Continued.

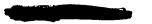


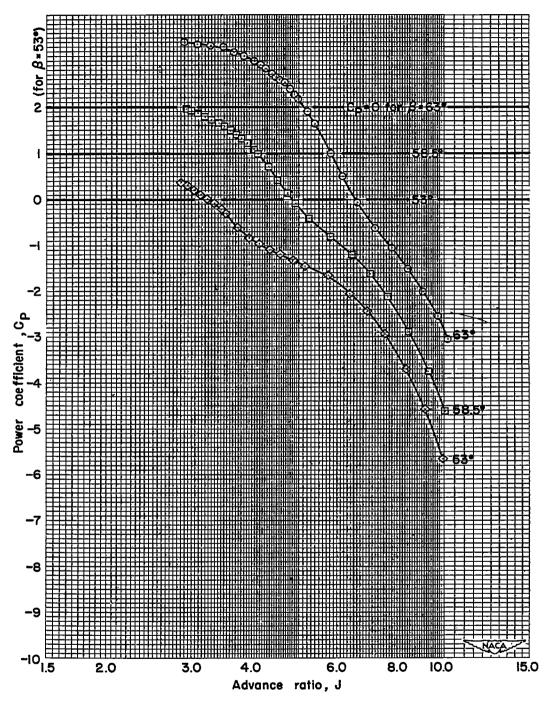


(e) M = 0.60

Figure 13.- Continued.

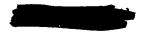






(f) M = 0.70

Figure 13.- Continued.



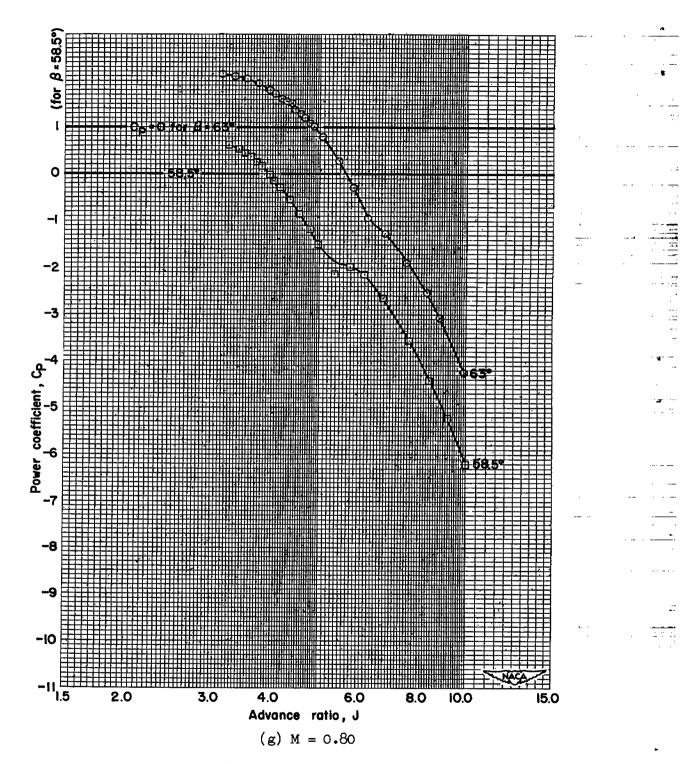


Figure 13.- Concluded.

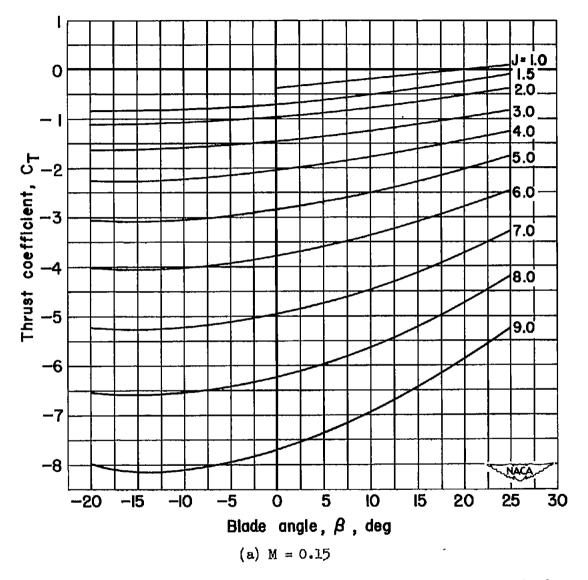


Figure 14.- The effect of blade angle on the negative-thrust characteristics of the propeller.

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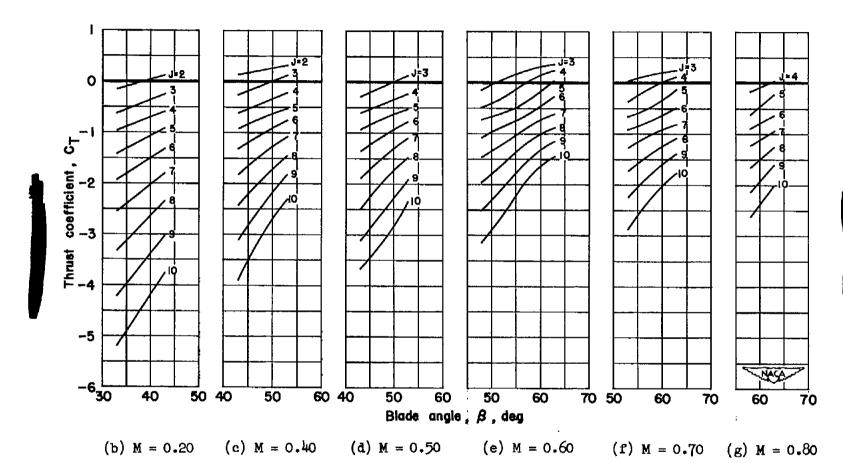


Figure 14.- Concluded.

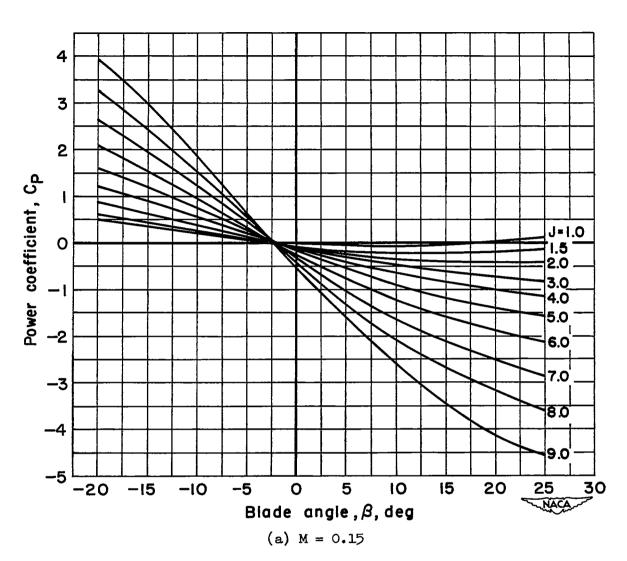


Figure 15.- The effect of blade angle on the power coefficients for the propeller in negative thrust.

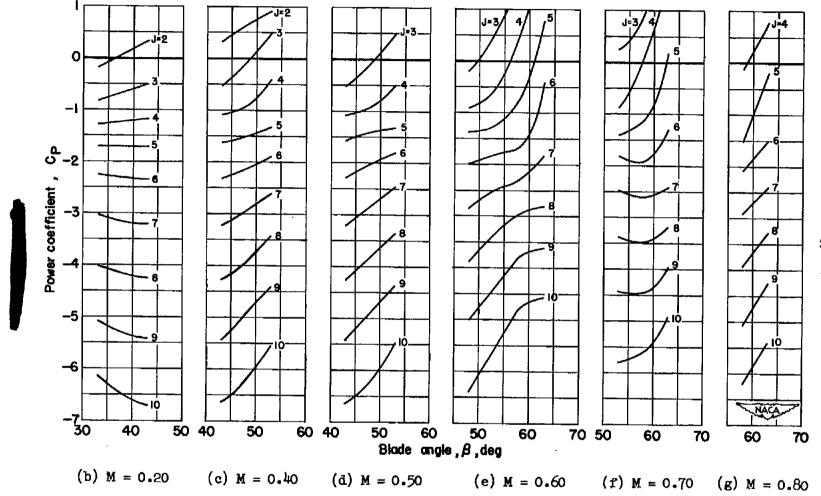


Figure 15.- Concluded.



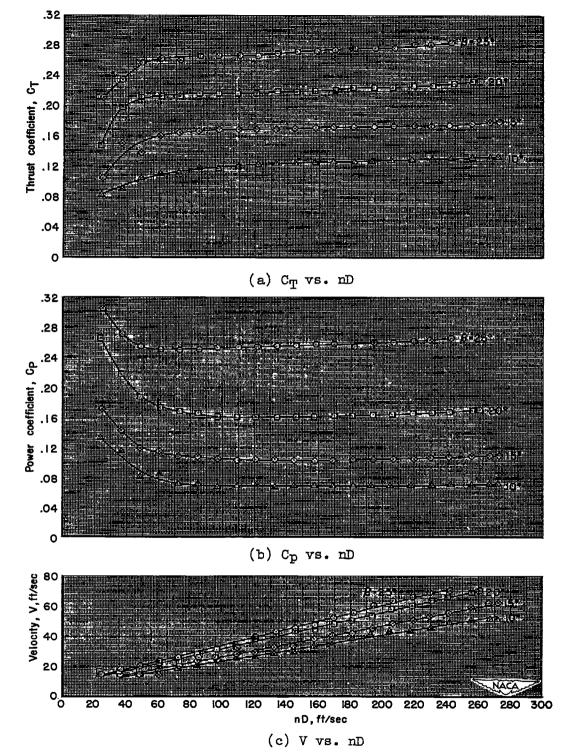


Figure 16.- Characteristics of the isolated propeller-spinner combination at near static conditions.





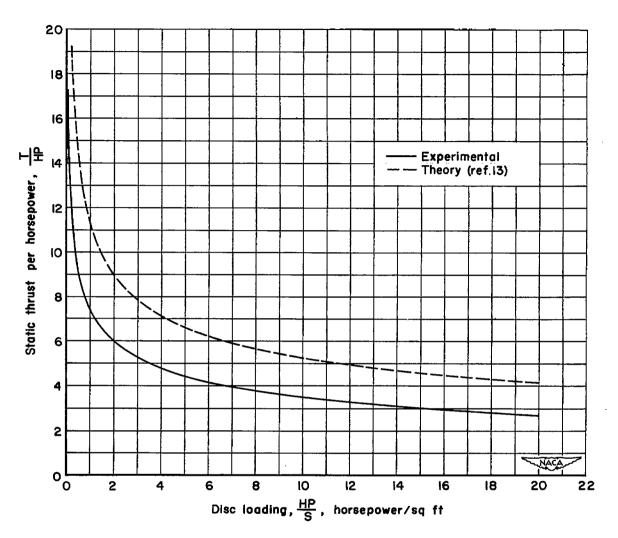


Figure 17.- Comparison with theory of the variation of sea-level static thrust per horsepower with power disc loading for the isolated propeller-spinner combination.



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